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ABSTRACT

This manual on bearings and seals is one of a series of power mechanics texts and visual aids for use in training for the servicing of automotive and off-the-road farm and industrial machines. Materials provide basic information and illustrations for use by vocational students and teachers as well as shop servicemen and laymen. Focusing on bearings, the first of two parts addresses topics such as types of bearings, loads on bearings, plain bearings (bushings), diagnosis of plain bearing failures, trouble shooting of plain bearings, anti-friction bearings, bearing capacities, types of ball bearings, types of roller bearings, types of needle bearings, maintenance of anti-friction bearings, diagnosis of failures, lubrication of anti-friction bearings, installation of anti-friction bearings, and trouble shooting of anti-friction bearings. Part 2 focuses on seals and addresses topics such as types of seals, how seals are selected, dynamic seals, radial lip seals, exclusion seals, clearance seals, ring seals, face seals, compression packings, molded packings, diaphragm seals, static seals, nonmetallic gaskets, metallic gaskets, static O-rings, engine cylinder head gaskets, sealants, hardening-type sealants, nonhardening sealants, and tape sealants. Each part concludes with test questions. Answers to the test questions are appended. (A supplementary set of 35mm color slides is also available--see availability note.) (LRA)

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ED185425

Bearings and Seals

JOHN DEERE

FOS
FUNDAMENTALS
OF SERVICE

CE 025 209

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TO THE READER

PURPOSE OF THIS MANUAL

The main purpose of this manual is to train the reader so that he can understand bearings and seals and service them with speed and skill. Starting with "how it works," we build up to "why it fails" and "what to do about it." This manual is also an excellent reference for the trained serviceman who wants to refresh his memory on bearings and seals. It is written in a simple form using many illustrations so that it can be easily understood.

WHAT IS "FUNDAMENTALS OF SERVICE"?

This manual is part of a series of texts and visuals called "Fundamentals of Service", or "FOS". These materials are basic information in power mechanics for use by teachers as well as shop servicemen and the layman. All types of modern equipment are covered — both automotive and off-the-road. Emphasis is on theory of operation, diagnosis, and repair.

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FOS — 54 Litho in U.S.A.

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BEARINGS / PART 1

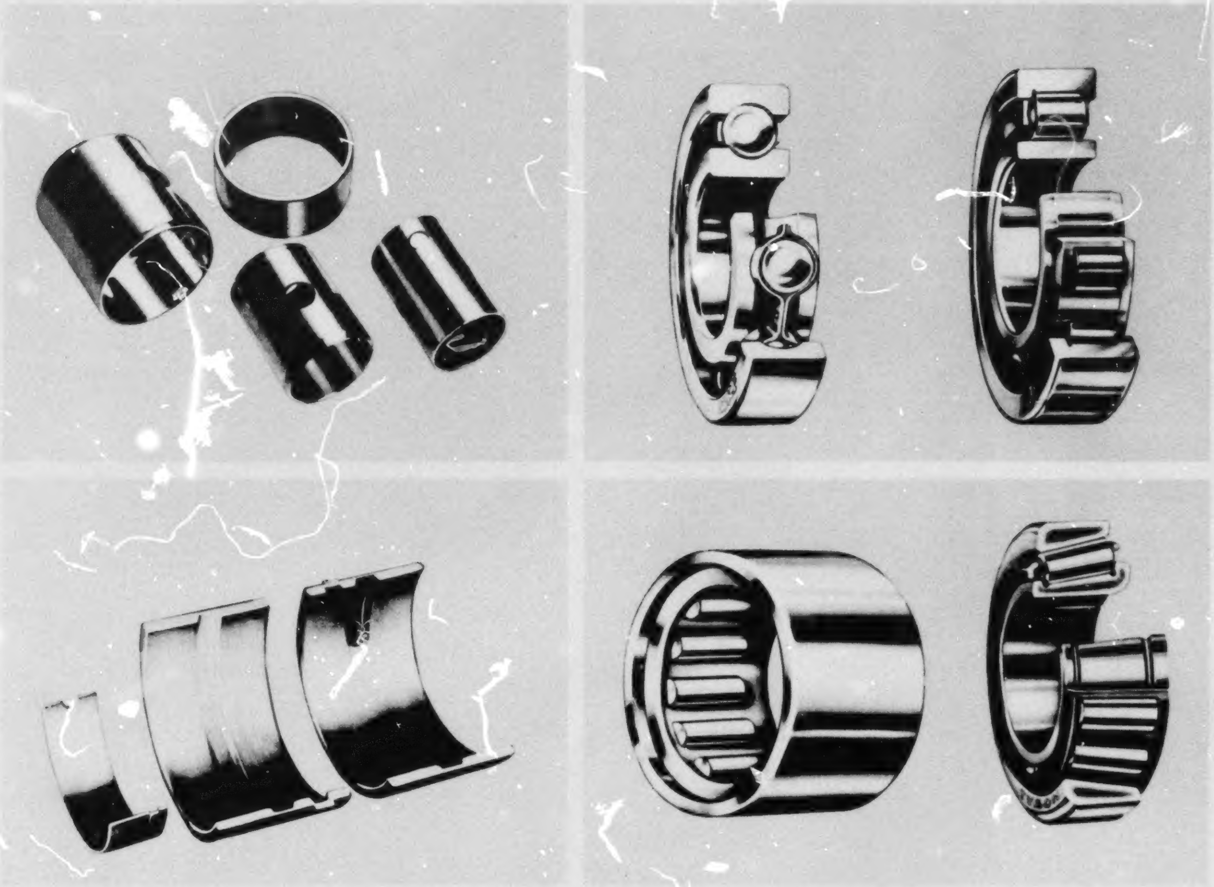


Fig. 1 — Every Type Of Bearing Is Used In Modern Machines

INTRODUCTION

Wherever a gear, wheel or shaft turns within its supports, provisions must be made to reduce friction and wear.

Bearings are used to do these jobs:

1. **Support the moving part.**
2. **Reduce friction.**
3. **Reduce wear.**
4. **Provide a replaceable wear surface.**

Bearings SUPPORT THE MOVING PART by carrying radial and axial loads while holding the part in alignment.

Bearings REDUCE FRICTION by providing either *sliding* contact (plain bearings) or *rolling* contact (anti-friction bearings). Usually bearings reduce the friction by means of a lubricant in addition to their basic design.

By reducing friction, bearings also REDUCE WEAR. They do this while providing a REPLACEABLE WEAR SURFACE which is more economical to replace than the gear, wheel, or shaft which the bearing supports.

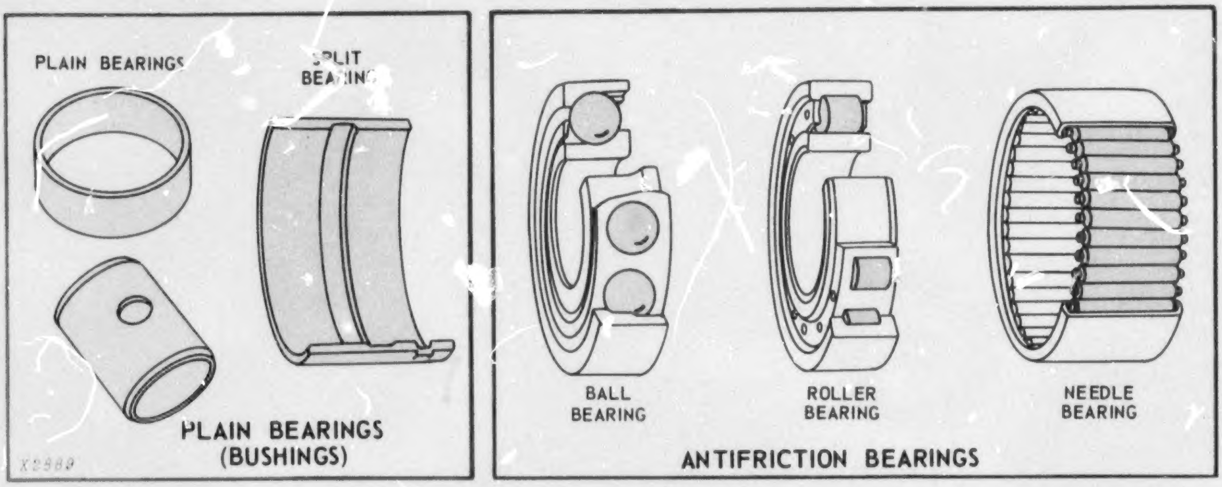

PLAIN BEARINGS
SPLIT BEARING
PLAIN BEARINGS (BUSHINGS)
X2889
BALL BEARING
ROLLER BEARING
NEEDLE BEARING
ANTIFRICTION BEARINGS

Fig. 2 — Two Basic Types Of Bearings

TYPES OF BEARINGS

There are two basic types of bearings:

- **Plain bearings (bushings)**
- **Anti-friction bearings**

PLAIN BEARINGS (Fig. 2) provide a *sliding* contact between the mating surfaces. They are also called "bushings" or "journal bearings."

ANTI-FRICTION BEARINGS (Fig. 2) give a *rolling* contact between mating surfaces. They do this by using ball or roller elements.

LOAD FORCES ON BEARINGS

Because bearings may be subjected to either *axial* or *radial* loads (Fig. 3), they are designed to be used for a specific application.

Radial bearings are used where only radial (sideways) loads are encountered. Thrust bearings are used where only axial (endways) loads are found. Some bearings are made to withstand both radial and axial loads.

Thrust loads are also carried by tapered roller bearings and some straight roller ball bearings. Due to their design, a radial load is converted to a thrust load in these bearings.

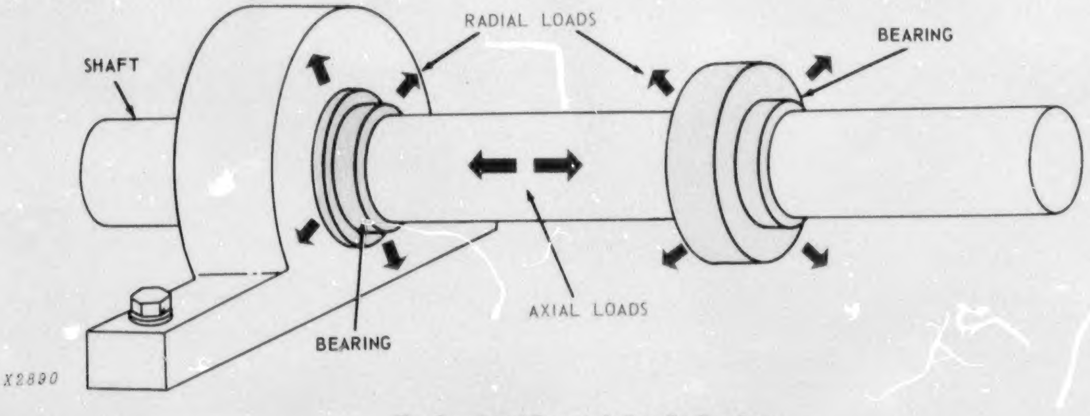

SHAFT
RADIAL LOADS
BEARING
AXIAL LOADS
BEARING
X2890

Fig. 3 — Load Forces Acting On Bearings

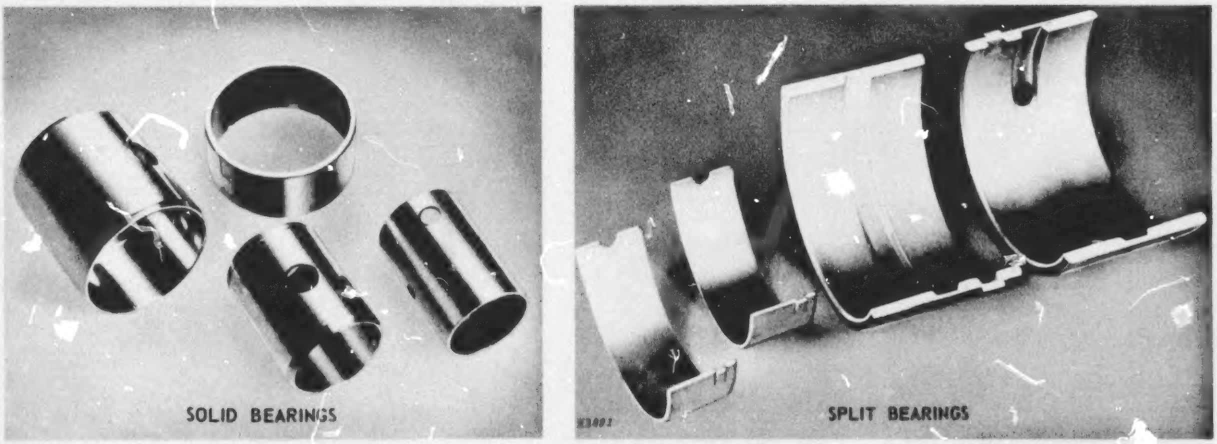


Fig. 4 — Typical Plain Bearings

ADVANTAGES AND DISADVANTAGES OF BEARINGS

Both plain and anti-friction bearings have advantages and disadvantages. Let's compare them.

PLAIN BEARINGS (BUSHINGS)

Advantages

1. *Require little space.*
2. *Low in cost.*
3. *Quiet operation.*
4. *Rigid construction.*

Disadvantages

1. *High-friction operation.*
2. *Requires continuous lubrication because they cannot be packed.*

ANTI-FRICTION BEARINGS

Advantages

1. *Low-friction operation.*
2. *Can be packed to reduce frequency of lubrication.*
3. *More versatile — many designs.*

Disadvantages

1. *Require more space than plain bearings.*
2. *Noisier operation.*
3. *Higher cost than plain bearings.*
4. *Less rigidity than plain bearings.*

Now that we have described bearings in general, let's examine each basic type in more detail. First — plain bearings.

PLAIN BEARINGS (BUSHINGS)

Plain bearings, as shown in Fig. 4 are often called *bushings.* Since "bearing" and "bushing" are synonymous terms, we will refer to all such designs as *bearings.*

Plain bearings take less space and usually cost less than anti-friction bearings. If frequent service is necessary and the location is accessible, plain bearings may be used.

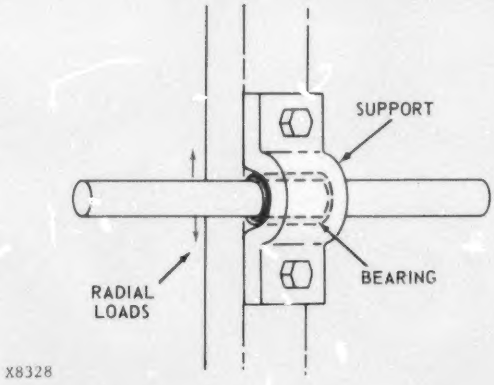


Fig. 5 — Bearing Designed For Radial Loads Only

However, anti-friction bearings are normally used where space is available, the location is not readily accessible, loads are heavy, speeds are high, less service is required, and cost is not the critical factor.

LOADS ON PLAIN BEARINGS

Before describing plain bearings, let's compare bearings designed for *radial* loads and *thrust* loads. In Fig. 5 notice that the bearing is supporting radial loads only.

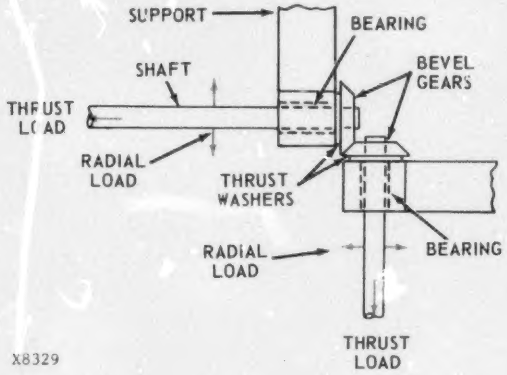

SUPPORT
BEARING
SHAFT
BEVEL GEARS
THRUST LOAD
RADIAL LOAD
THRUST WASHERS
RADIAL LOAD
BEARING
THRUST LOAD
X8329

Fig. 6 — Thrust Washers Used With Radial Load-Type Bearings

Radial load-type bearings may be used in conjunction with thrust washers, as shown in Fig. 6, when both thrust and radial loads are present.

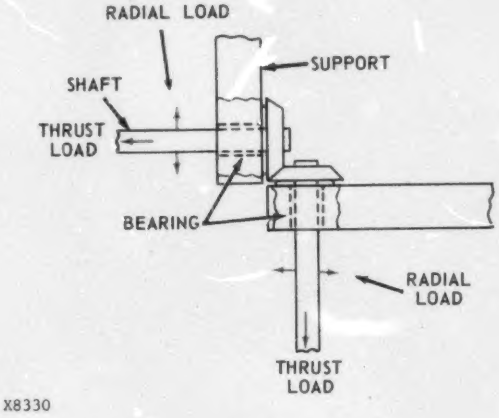

RADIAL LOAD
SUPPORT
SHAFT
THRUST LOAD
BEARING
RADIAL LOAD
THRUST LOAD
X8330

Fig. 7 — Bearings Designed For Both Radial And Thrust Loads

Bearings that support radial loads as well as axial loads are shown in Fig. 7.

TYPES OF PLAIN BEARINGS

Fig. 8 below shows some typical plain bearings. They are described on the next page.

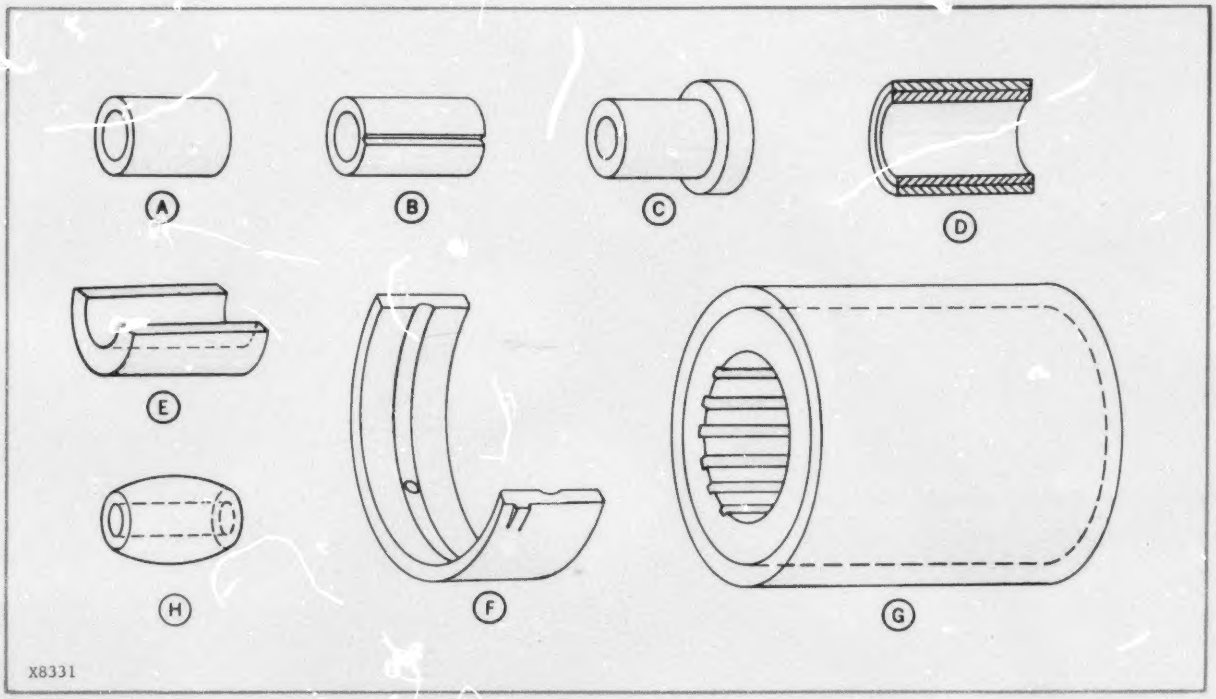


Fig. 8 — Types Of Plain Bearings

A. **Solid bearing or sleeve.** *These bearings are usually made of copper, brass, bronze, or plastic. They support only radial loads.*

B. This type of **split bearing** *is initially formed as a strip of the material and then rolled into the final shape. Usually made of copper, bronze, or steel. It also supports only radial loads.*

C. This type of **thrust bearing** *is designed for both radial and thrust loads. Usually made of bronze or plastic.*

D. This type of **split bearing** *is normally constructed with a steel back lined with bronze, plastic or babbit. It supports only radial loads.*

E. This is a **split-type bearing** *and may be constructed of wood, plastic, rubber, or sintered metal. It also may be made of cast iron. This bearing also supports only radial loads.*

F. This type of **split bearing** *is normally used for engine crankshaft bearings. It is usually made of a steel or bronze back with a softer babbit lining. However, there are different types of linings such as copper-lead, tin, or silver which will be discussed later. Variations of this bearing will support both radial and thrust loads.*

G. This **solid bearing** *has a fluted rubber structure supported by a rubber shell. The flutes in the rubber form a series of passages that allow the lubricant, normally water, to flow through the bearing. This bearing supports only a radial load.*

H. This **self-aligning bearing** *has a spherical outer surface so that it can align itself with the shaft as it may vary its position. It may be mounted in a spherical housing or in a flexible mounting such as rubber. It often contains a groove to prevent bearing rotation.*

MOUNTINGS FOR PLAIN BEARINGS

Plain bearings are usually installed in their supports with a *press fit* or a shrink fit. This fit prevents the bearing from rotating within its mounting, assures good heat transfer which is important to bearing life, and assures good concentricity of the bearing.

The running clearance is between the inside surface of the bearing and the O.D. of the shaft.

Some plain bearings are mounted with seals which retain the lubricant and exclude dirt. (See the section on "Seals" later in the manual.)

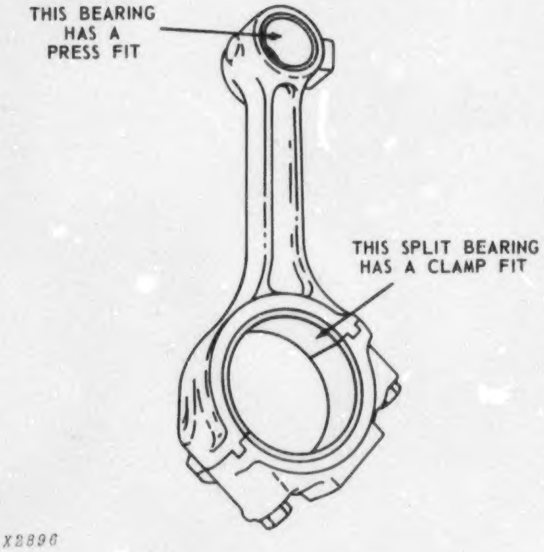

THIS BEARING HAS A PRESS FIT
THIS SPLIT BEARING HAS A CLAMP FIT
X2896

Fig. 9 — Two Types Of Bearing Installations

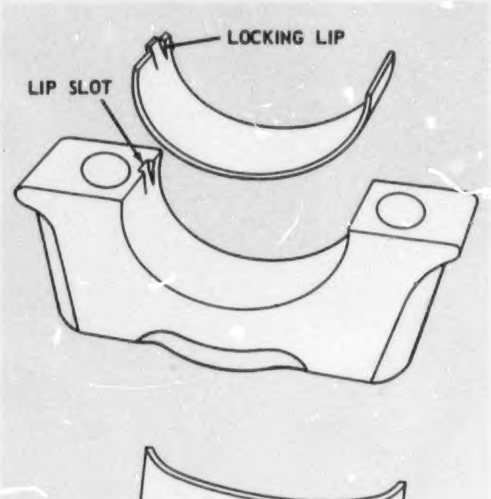


Fig. 10 — Two Types Of Bearing Locks

In Fig. 9 you can see two types of bearing installations in an engine connecting rod.

The upper eye of the connecting rod has a *press-fit* bearing which in this case requires reaming after installation. This reaming is required to size the bearing to the piston pin.

On the other end of the connecting rod is a split bearing that is *clamped* together.

Split bearings are usually locked in place to prevent rotation with the shaft. Two methods of locking are shown in Fig. 10.

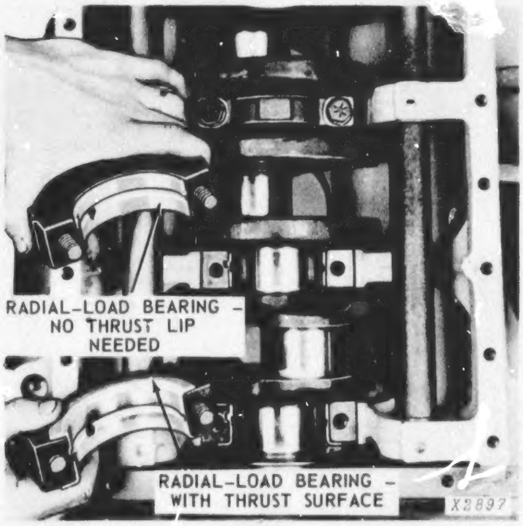

RADIAL-LOAD BEARING – NO THRUST LIP NEEDED
RADIAL-LOAD BEARING – WITH THRUST SURFACE
X2897

Fig. 11 — Radial And Thrust Split Bearings

While we are talking about split bearings, notice the difference between radial and thrust split bearings as shown in Fig. 11.

Some bearings have a running clearance between the shaft and bearing in addition to clearance between the bearing O.D. and its housing. These bearings are termed *floating bearings* and are used in such devices as turbochargers where the speed is very high (80,000 rpm and up) and the load is light. They are protected by a "cushion" of lubricant.

MATERIALS IN PLAIN BEARINGS

Bearings are constructed of a variety of materials. Some of these are: Wood, plastic, cast iron, chilled cast iron, soft steel, hardened steel, copper, brass, bronze, copper-lead, aluminum, babbit, and sintered metal (iron, brass, copper, graphite, phenolic material, and nylon).

The material used in a bearing depends on the space available, the speed at which the shaft turns, the amount of load it carries, the type of lubricant to be used, and, in many cases, the cost of the installation.

1. **Wood bearings** are sometimes used on large slow-moving shafts, such as conveyors, which are subjected to excessive amounts of dirt. They are not costly, require a minimum of attention, have relatively long life, and are easily replaced.

2. **Cast iron and chilled (hardened) cast iron bearings** are usually used on slow-moving shafts that operate in excessively dirty conditions. Since these bearings are resistant to the wear caused by dirt, they are used on such implements as disk harrows, plows, and other slow-moving machines.

3. **Soft steel bearings** usually support shafts having little movement and where support is the main objective.

Hard steel bearings are used to support large slow-moving shafts or as bearings in slow-moving wheels and the like.

4. **Copper, brass, and bronze bearings** are widely used to support shafts and gears in machines. Normally, the material is determined by the application; each metal has different wearing characteristics. Bronze is probably the most commonly used.

5. **Copper-lead bearings** are an alloy of the two metals. They are normally used where the rigid support of the copper is required in addition to the good qualities of lead. They are used as a backing for babbit, tin, silver, etc. in engine crankshaft bearings. They operate longer with less attention than many other metals.

6. **Babbit bearings** are an alloy of lead, tin, antimony, and often other metals. Being relatively soft, babbit allows some particles of foreign matter to become imbedded in it. This prevents wear on the shaft which would otherwise occur if the particles were not imbedded. These bearings are most commonly used as engine crankshaft and camshaft bearings.

7. **Aluminum bearings** have many applications where weight is a factor. Other uses are for high speed shafts and also some engine crankshaft bearings.

8. **Sintered metal bearings** (iron, brass, bronze, graphite, etc.) are commonly used on a machine where minimum service is desired. They are constructed by subjecting fine particles of the material to tremendous pressure and heat. These bearings can absorb their lubricant and thus require very little service.

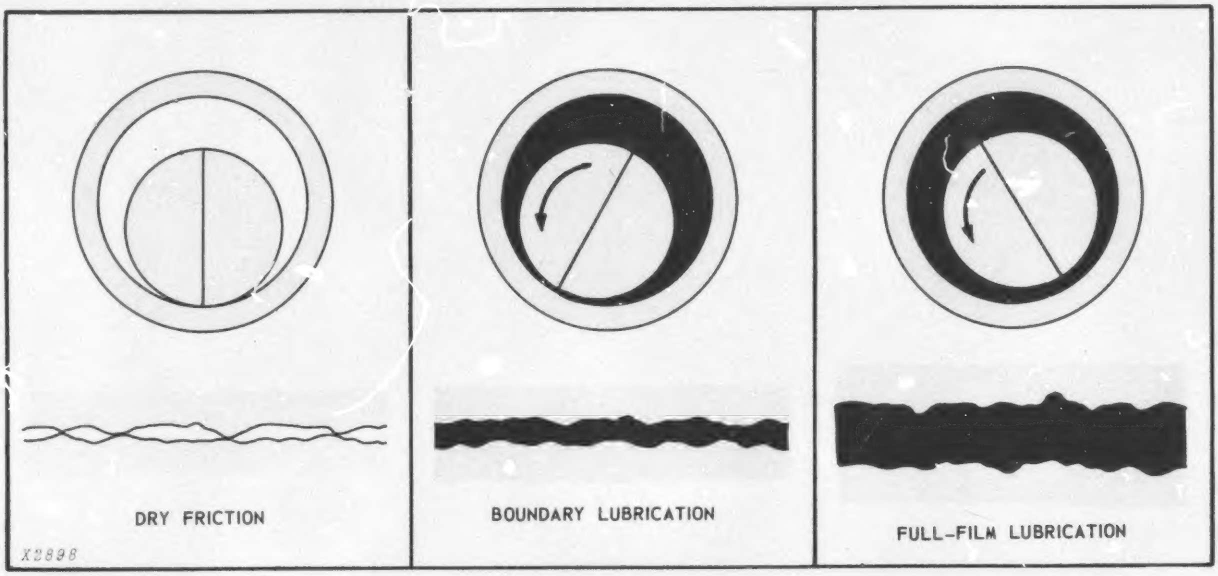


Fig. 12 — Three Types Of Friction

9. Plastic bearings (phenolic, teflon, nylon, etc.) are becoming increasingly popular for bearings because of their resistance to corrosion, quiet operation, and conformability. They are also partly self-lubricating, which reduces the need for lubrication.

Laminated phenolic bearings consist of cotton fabric, asbestos, or other fillers, bonded with phenolic resin. They have good strength and shock resistance. Being relatively quiet, they are often used to make engine camshaft gears where noise may be a factor. However, precautions must be taken for adequate cooling as they are poor conductors of heat.

10. Rubber bearings are normally used as bearings for propeller and rudder shafts on boats and ships, hydraulic turbines, pumps, sand and gravel washers, and other machines which handle water or slurries. The resilience of rubber helps to reduce vibration and give quiet operation. It also allows operation with larger clearances and helps to compensate for mis-alignment.

LUBRICATION OF PLAIN BEARINGS

Lubricants are used to reduce friction and wear in bearings. The less friction, of course, the less wear will result.

Three states of friction or lubrication may exist between sliding surfaces (Fig. 12):

- **Dry friction**
- **Boundary lubrication**
- **Full-film lubrication**

DRY FRICTION is when no lubricant is present between the contacting surfaces as in crawler track pins and bushings.

BOUNDARY LUBRICATION is when the lubricant is a thin film between the sliding surfaces. Only where movement is relatively slow, and loads are light can this type of friction be acceptable.

FULL-FILM LUBRICATION separates the sliding surfaces completely with hydrodynamic pressure. This provides the low friction and long wear life which is desired.

Notice in Fig. 12, the three positions of the shaft as it changes from boundary lubrication to full-film lubrication. (The shaft load is downward). As the shaft begins rotating as shown in boundary lubrication, it tries to climb the side of the bearing. At moderate speed, the shaft returns and then begins to move to the opposite side as hydrodynamic pressure increases.

Full lubrication can only be achieved by a combination of the right lubricant, good bearing design, and at least a moderate rotary speed.

If the proper lubricant is not used, poor bearing performance will result.

For example, if the viscosity is too light, the fluid will not support the shaft and metal-to-metal contact will occur.

If the lubricant is too heavy, the bearing will heat because of the friction created by the churning lubricant. This heat, if extremely high, will cause bearing failure.

How Lubricant Is Distributed To Bearings

The bearing must have these characteristics in order to perform well:

1. *It must have a means of distributing the lubricant.*
2. *Oil clearance must be correct to fit the shaft well.*
3. *The bearing surface must be compatible with the shaft, the lubricant, and the speed of rotation.*

OIL GROOVES

Oil grooves are necessary to insure that the bearing receives adequate distribution of lubricant. Several designs are shown below in Fig. 13.

BEARING CLEARANCE

Bearing clearance is very important. it depends upon load, speed, and type of lubricant.

If too little clearance is allowed, the load and the speed of shaft rotation will cause the bearing to overheat and fail.

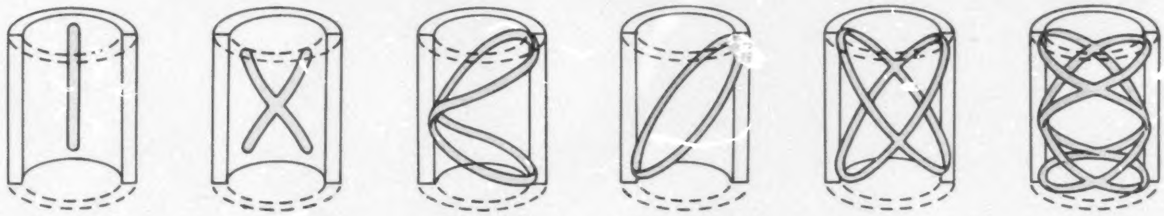
Too much clearance will allow the lubricant to leak out and result in too little hydrostatic pressure which will cause the surfaces to rub and wear.

BEARING SURFACE COMPATIBILITY

Fig. 14 on the next page shows the three states of lubrication. Each condition is determined by the viscosity of the lubricant, speed of shaft rotation, and smoothness of the mating surfaces.

Surfaces in Contact is caused by using a light-viscosity lubricant to support the shaft or by surfaces too rough to be separated by the recommended lubricant.

Surfaces Separated by Lubricant is the minimum lubrication requirement to prevent actual contact of mating surfaces. This condition exists with relatively slow speeds of rotation. However, if a lubricant with heavy viscosity is used here and shaft speeds are too fast, excessive heat will be generated by the friction of the churning lubricant.



USED IN GENERAL APPLICATIONS

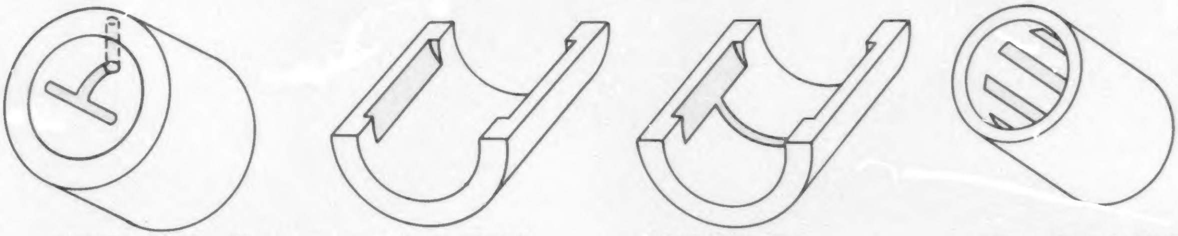
ALSO USED IN GENERAL APPLICATIONS

USED FOR FRACTIONAL HORSEPOWER MOTORS

USED WHEN OIL IS SUPPLIED NEAR END OF BEARING

USED FOR GREASE LUBRICATION

ALSO USED FOR GREASE LUBRICATION



FEEDER GROOVE AND AXIAL DISTRIBUTING GROOVE USED FOR LARGE, SLOW SPEED BEARINGS.

CHAMFERED RECESS IN SPLIT BEARING DISTRIBUTES OIL ALONG SHAFT. USED IN ENGINES.

CIRCUMFERENTIAL GROOVE AND CHAMFERED RECESS IMPROVES OIL FILM COOLING. USED IN ENGINE BEARINGS.

USED FOR PULSATING LOADS WITH LIMITED SHAFT ROTATION.

X2899

Fig. 13 — Oil Groove Designs For Plain Bearings

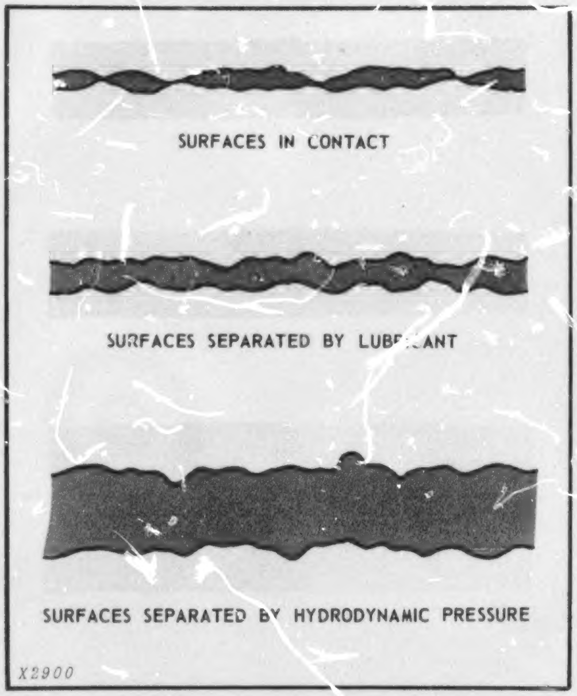

SURFACES IN CONTACT
SURFACES SEPARATED BY LUBRICANT
SURFACES SEPARATED BY HYDRODYNAMIC PRESSURE
X2900

Fig. 14 — Lubricant Between Sliding Surfaces

Surfaces Separated by Hydrodynamic Pressure is the ideal state of lubrication. The surfaces of the mating parts, the speed of rotation, and the viscosity of the lubricant all affect the ability to achieve this condition. If the surface is too smooth and the shaft speed too slow, the hydrodynamic pressure will not be sufficient to lift the shaft; the surfaces may contact or be barely separated by the film of lubricant.

Methods Of Lubrication

Lubricants may be applied to plain bearings in many different ways. These methods vary from simple hand operations to more complex pressure systems as used in modern engines.

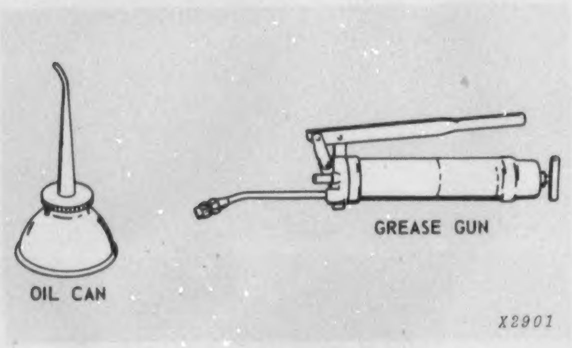


Fig. 15 — Two Types Of Hand Lubrication

Two methods of lubrication that are most familiar are the oil can and grease gun shown in Fig. 15. The oil can is used to apply lubricant directly on the parts or in an oil cup attached to the bearing. The grease gun is used on the fittings shown in Fig. 16.

A. Conventional Ball-Check Fitting

B. Pressure Relief Fitting

C. Pressure Shut-Off Fitting

D. Button-Head Fitting

E. Hydraulic Measuring Fitting

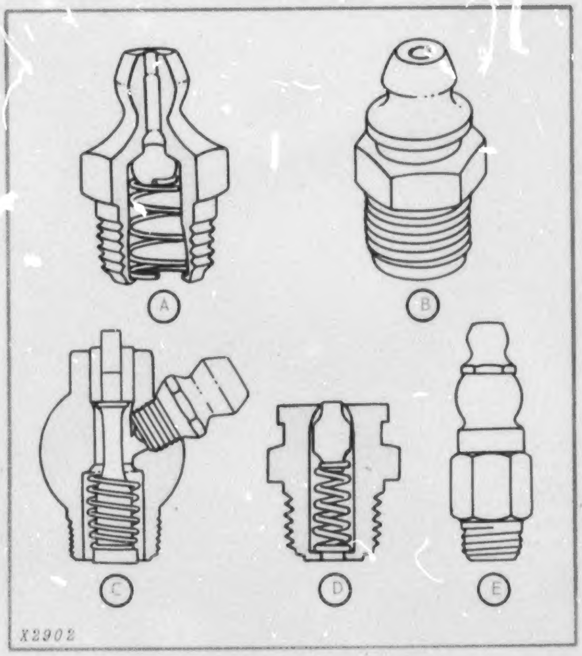


Fig. 16 — Types Of Grease Fittings

Some of the most common types of grease fittings are shown in Fig. 16. Each fitting is designed for a particular requirement. Some fittings measure quantity or pressure and others relieve excessive pressure.

Another type of lubrication device is the central grease system which lubricates several, usually hard-to-reach, bearings with a few strokes of a plunger.

One of the most common methods of oil lubrication is the oil bath splash system, such as shown in Fig. 17 on the next page. This method is used in simple engines, transmissions, differentials, and other components which can hold a large supply of lubricant. Rotation of gears splashes oil onto the vital bearing areas.

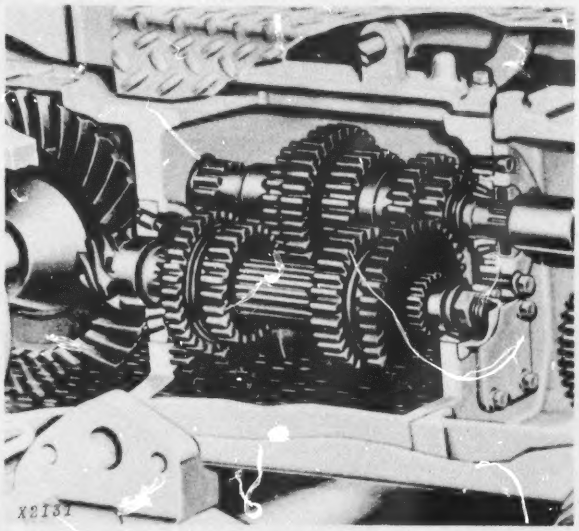


Fig. 17 — Oil Bath Splash System Used In Transmissions

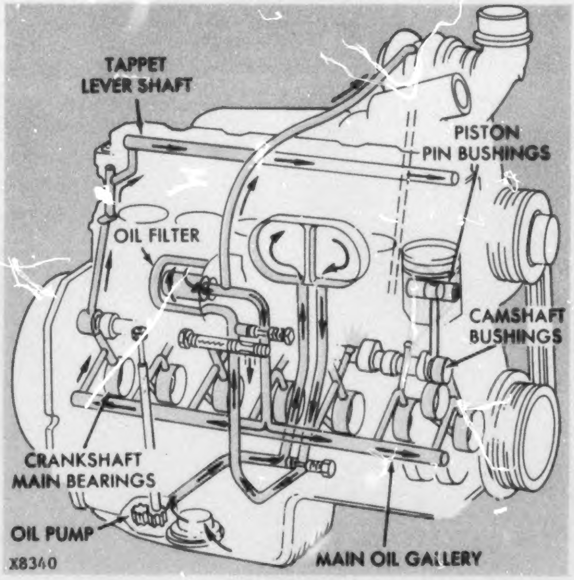

TAPPET LEVER SHAFT
PISTON PIN BUSHINGS
OIL FILTER
CAMSHAFT BUSHINGS
CRANKSHAFT MAIN BEARINGS
OIL PUMP
X8340
MAIN OIL GALLERY

Fig. 18 — Pressure-Feed Oil System In A Typical Engine

Probably the best method of providing adequate lubrication to bearings is the pressure-feed system. In Fig. 18 you can see how this method is used to supply oil to critical bearings in an engine. Some complex machines also use a pressure system in their transmissions.

NOTE: For more information on lubricants, see the FOS manual on "Fuels, Lubricants, and Coolants."

REPAIR AND REPLACEMENT

Plain bearings are usually replaced when damaged or worn — seldom are they repairable.

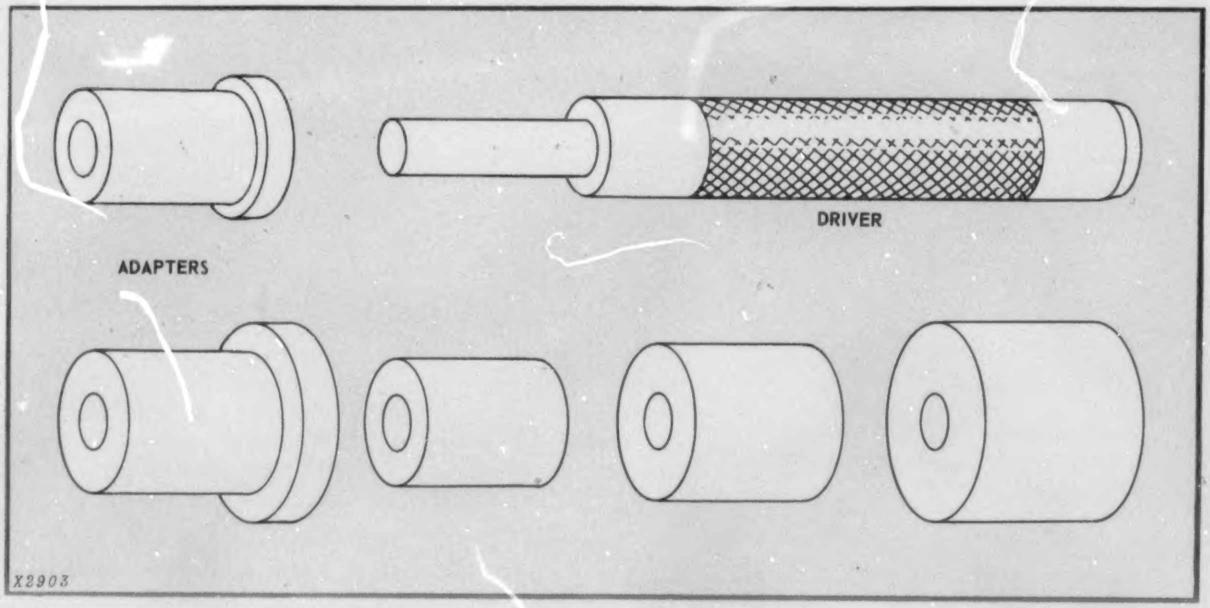

DRIVER
ADAPTERS
X2903

Fig. 19 — Bearing Driver And Adapter

Replacing Simple One-Piece Bearings

Bearing removal or installation is relatively simple with one-piece bearings. However, take precautions to prevent damage to the bore in which the bearing is installed. A length of cold rolled steel rod can be used to drive the bearing in or out. Or, use a round nose cold chisel to cut a channel lengthwise through the bearing; then the bearing can easily be driven out. However, use this method only if no other method is available.

A special driver, such as in Fig. 19 is more practical and less liable to damage the bore. These can be purchased from your tool supplier with various adapters for different size bearings.

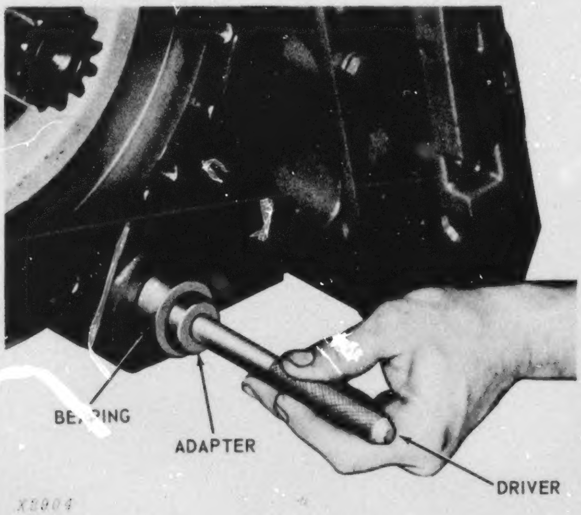


Fig. 20 — Bearing Installation With A Driver And Adapters

Use extreme care when installing bearings (Fig. 20). The bore must be clean and free from burrs. Drive the bushing *straight* into the bore. If it is "cocked" when driven in, it will be distorted and damaged.

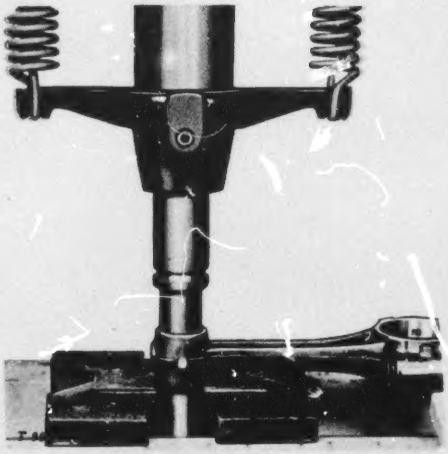


Fig. 21 — Installation Of Bearing With A Press

When possible, use a press as shown in Fig. 21 to install bearings. This assures that the bearing is pressed into its bore accurately.

In some cases it is necessary to ream a bearing to size where a critical fit is required. A pilot and reamer are used to size the bearing bore as shown below in Fig. 22. If a pilot is not used, the reamer may not start correctly. Always be sure that the reamer or hone is inserted straight into the bearing bore. If not, the bore will not be square with the shaft. Not only will there not be a full bearing, but rapid wear will occur.

Replacing Split Bearings

Split bearings are most often used in engine crankshafts; they are also used in many other applications. However, the same basic principles apply when replacing all these types of bearings.

NOTE: For more information about engine bearing service, refer to the FOS manual on "Engines."

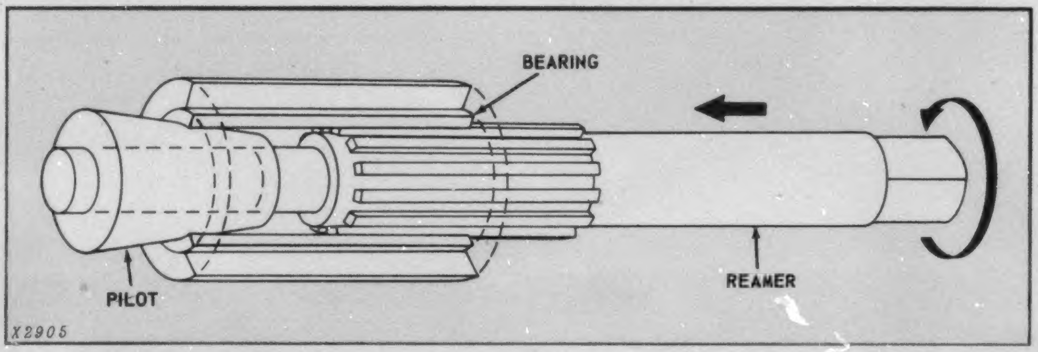


Fig. 22 — Reaming Bushing To Size

Measuring Bearing Clearance

Before new bearings can be installed, you must determine the condition of the shaft. If the shaft surface is too worn or rough, it may have to be reground or replaced. Check for journals that are tapered or out-of-round. If regrinding of crankshaft is necessary, see Fundamentals of Service — Engines (Chap. 2) for the correct procedure.

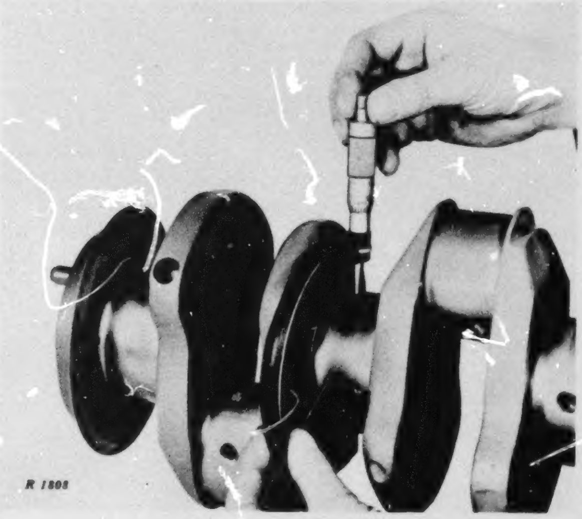


Fig. 23 — Measuring Shaft Wear

After the shaft has been found to be in good condition, measure it in several places around the shaft to determine amount of wear (Fig. 23). Refer to your machine Technical Manual for wear limits.

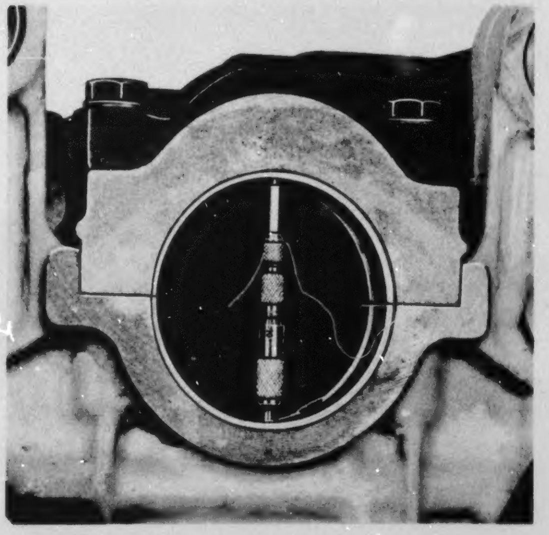


Fig. 24 — Measuring Bearing Clearance

Install the bearings and tighten to specified torque. Using an inside micrometer, measure the inside diameter of the bearing (Fig. 24). Compare the reading with the outside diameter of the shaft. Determine the clearance by subtracting the shaft diameter from the bearing inside diameter. Refer to specifications to determine the correct clearance.

Under-sized bearings may have to be installed if too much wear has occurred.

Measuring Bearing Clearance Using Plastigage

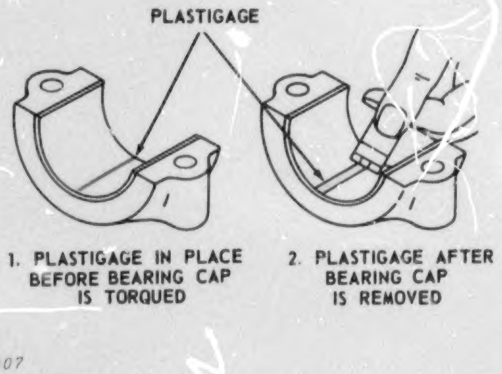

PLASTIGAGE
1. PLASTIGAGE IN PLACE BEFORE BEARING CAP IS TORQUED
2. PLASTIGAGE AFTER BEARING CAP IS REMOVED
X2907

Fig. 25 — Using Plastigage To Measure Bearing Clearance

Another method of measuring bearing clearance is by using "Plastigage." This is a plastic thread which "crushes" to the exact clearance when the bearing cap is fully tightened. While this method will give the bearing clearance, it will not tell you whether the wear is on the bearing or on the shaft.

Installing Split Bearings

Extreme care must be taken when installing split bearings. The bearing must be round and true, since there must be perfect contact between the inside of the bearing seat and the outside of the bearing. This is one factor that is often overlooked when these bearings are installed. If excellent contact does not exist, the heat will not flow from the bearing to its support and the bearing may melt. This is one reason why shims must not be used between the bearing and its seat to correct wear. When installing the bearing, be careful that it does not cover any oil holes and that the locking devices are in correct relationship (Fig. 26 on next page).

The factor of heat dissipation is one reason for bearing *crush.* Crush means that each half of the bearing inserts extends one or two thousandths of an inch beyond the bearing seat bore as shown

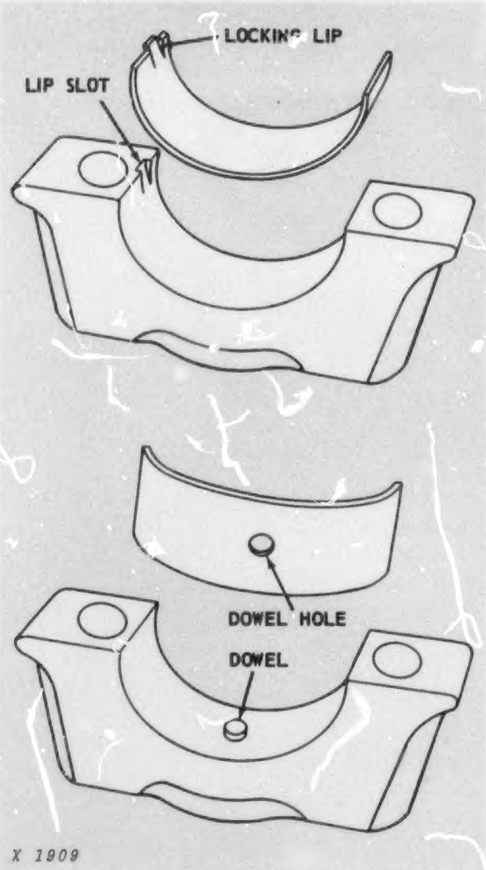

LOCKING LIP
LIP SLOT
DOWEL HOLE
DOWEL
X 1909

Fig. 26 — Bearing Locks

below in Fig. 27. Then when the cap screws of the bearing cap are tightened to the specified torque, the insert is forced to seat solidly in the bearing seat.

Another reason for crush is to insure that the bearing remains round. If not tightly held on the edge, it might distort as illustrated in exaggerated form in Fig. 28 on the next page.

Still another reason for crush is to avoid any possible movement of the bearing in the seats. If the bearing becomes loose, it could oscillate in its seat and wear on the outside. This could interfere with oil control and heat transfer. Any dirt between the insert and its seat would have the same effect.

On the other hand, the amount of crush must not be excessive — only .001 or .002 inch (0.025 or 0.05 mm). If it is more than .002 inch (0.05 mm), the insert will be distorted as illustrated in Fig. 28, when the cap is tightened. The bearing will buckle and result in increased friction and heat — leading to bearing failure.

Also inspect joint surfaces of cap, rod, and block for excessive wear, nicks or other irregularities. Also use correct procedures for tightening capscrews. These items all have an effect on proper bearing crush and joint fit.

Split bearings are extremely accurate as they come from the manufacturer and must be handled with care. Always use the precise size required and install without alteration or fitting.

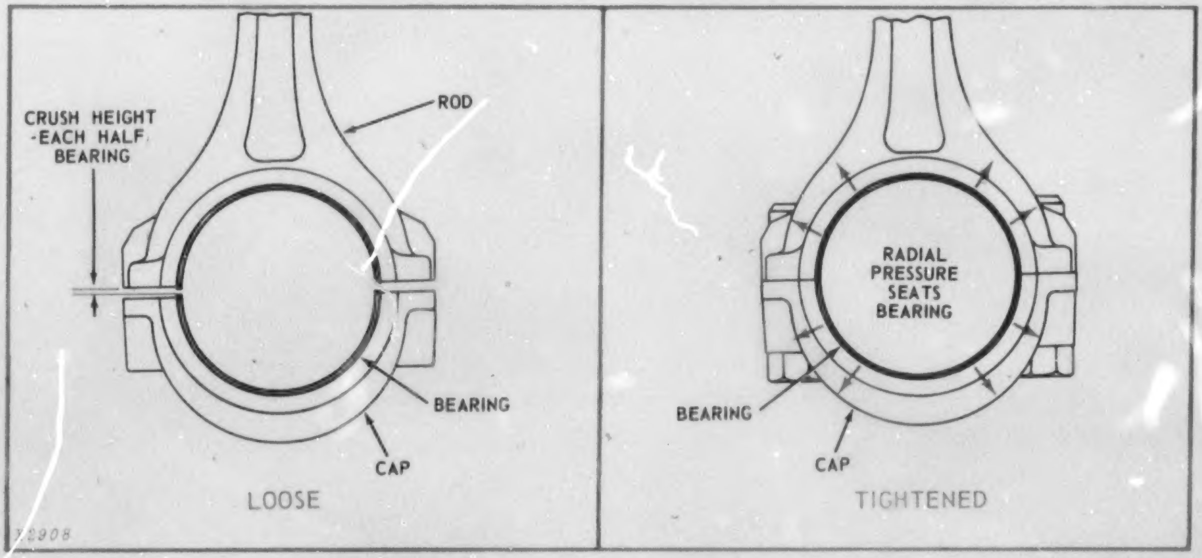

CRUSH HEIGHT
-EACH HALF
BEARING
ROD
BEARING
CAP
LOOSE
RADIAL
PRESSURE
SEATS
BEARING
BEARING
CAP
TIGHTENED
X 2908

Fig. 27 — Bearing "Crush"

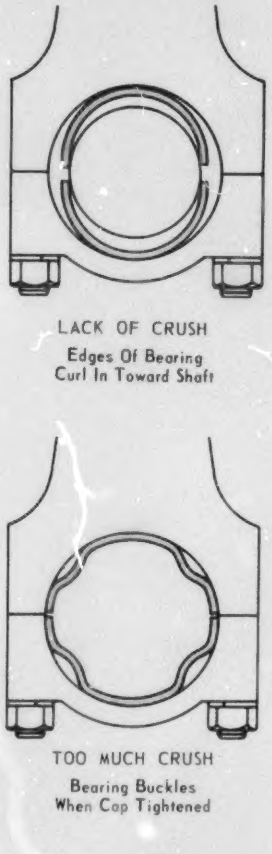

LACK OF CRUSH
Edges Of Bearing Curl In Toward Shaft
TOO MUCH CRUSH
Bearing Buckles When Cap Tightened
X2909

Fig. 28 — Effects Of Improper Crush

DIAGNOSING PLAIN BEARING FAILURES

When replacing damaged bearings, it is vital to determine their *cause* of failure. Otherwise, failures may occur again in a very short time.

Most bearing failures can be linked to *specific* causes. One bearing manufacturer found that causes of failures ranked as follows:

1. **Dirt**
2. **Lack of lubrication**
3. **Improper Assembly**
4. **Misalignment**
5. **Overloading**
6. **Corrosion**

When worn or damaged bearings are removed, examine them using this section as a guide.

Oil Starvation

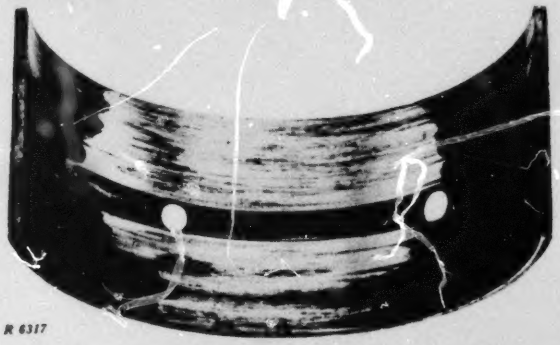


Fig. 29 — Oil Starvation Caused This Damage

Oil starvation was the cause of damage to the bearing shown in Fig. 29. Lack of oil can occur immediately after overhaul. This is when priming of the lubricating system is vital to assure initial lubrication.

After break-in, other things can happen. Both local and general oil starvation can result from external leaks and mechanical supply failures. Blocked oil suction screen, oil pump failure, oil passages plugged or leaking, failed pressure relief valve springs, or badly worn bearings can stop the circulation of lubricating oil.

A mislocated oil hole will also cut off the oil supply to a bearing, causing rapid failure. Always check to be sure that the oil hole in the bearing is in line with the oil supply hole.

Also, in the case of engines, the oil supply may become diluted by seepage of fuel into the crankcase from a defective fuel pump. This will reduce the oil's film strength and the increased friction will score the bearings.

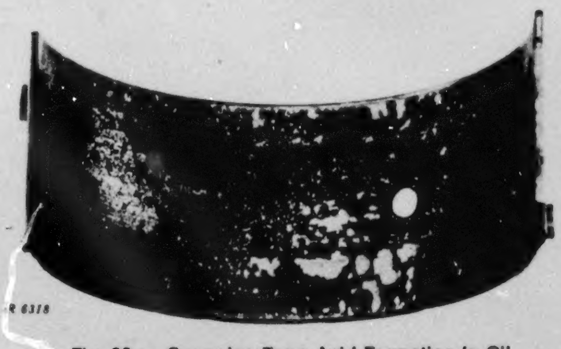


Fig. 30 — Corrosion From Acid Formation In Oil

Corrosion from acid formation in the oil is seen by a finely pitted surface and large areas of deterioration (Fig. 30).

Corrosion occurs when oil temperature goes above 300°F (149°C) and when excessive blow-by occurs in engines. It is also aggravated by condensation. In some cases, incorrect lubricant will also cause corrosion.

Prevent corrosion in engines by changing oil at correct intervals and by selecting oil of the proper quality and classification for the machine and type of service. Follow the manufacturer's recommendations.

Dirt

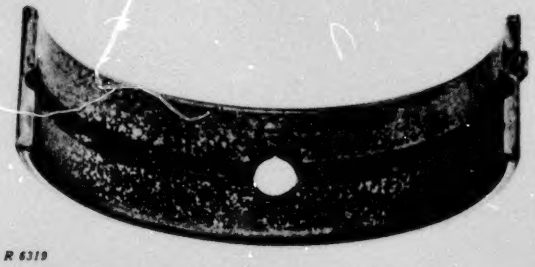


Fig. 31 — Damage From Dirt Embedded In Bearing

Large *dirt* particles can embed in the soft bearing material (Fig. 31). This causes wear and decreases the life of both the bearing and its journal.

Prevent this by cleaning the area surrounding the bearing thoroughly during bearing installation and by proper maintenance of both air and oil filters, if used.

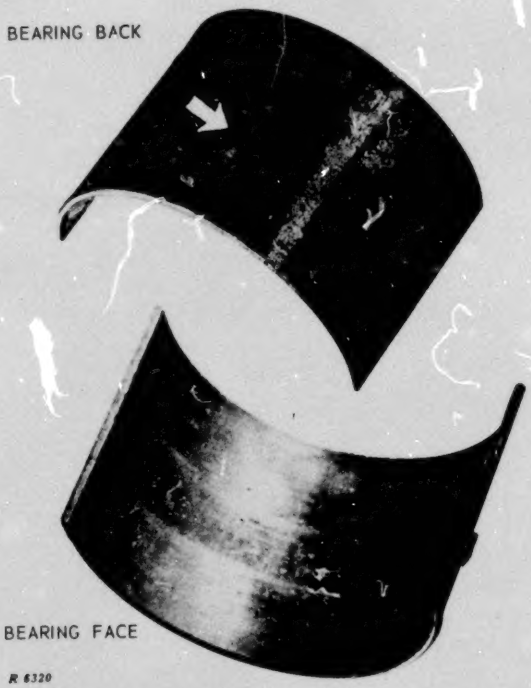


Fig. 32 — Particle Of Dirt Left From Improper Cleaning

A particle of dirt was left (Fig. 32, arrow) during bearing installation. It remained behind this bearing on its cap to push the bearing inward at one

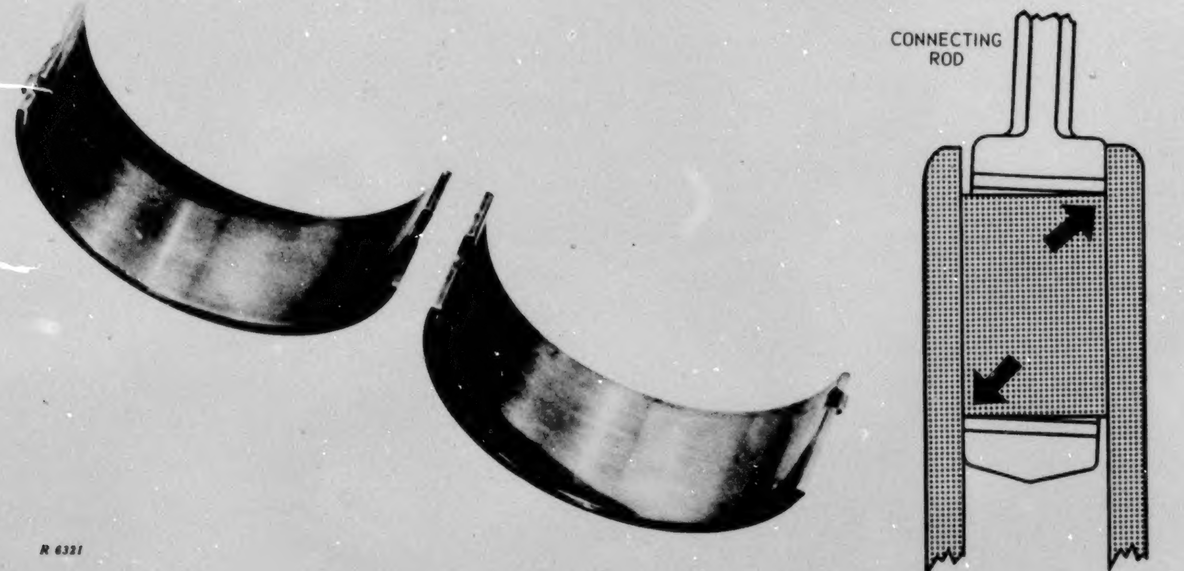


Fig. 33 — Excessive Wear Caused By Misalignment

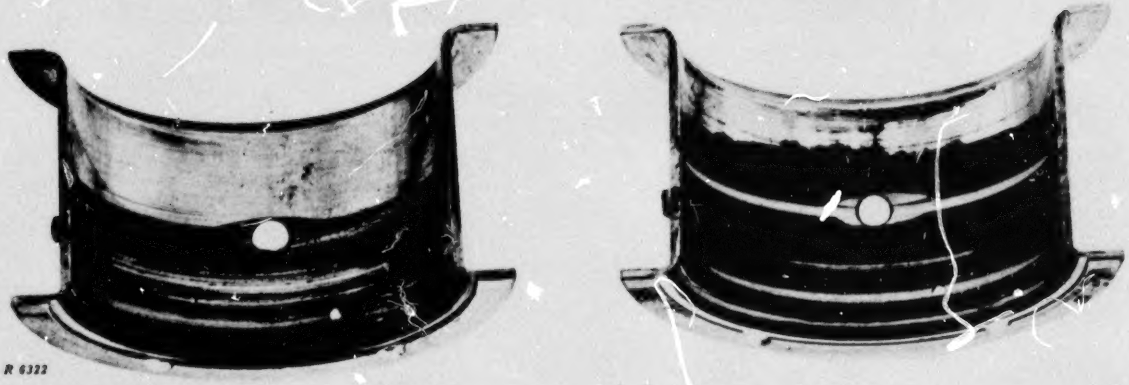


Fig. 34 — Wear On One Edge Of Bearing Caused By Tapered Journals

point, thus increasing localized pressure and heat. This damage started because of improper cleaning of a bearing. Dirt was allowed to remain and create an area of excessive heat that led to this damage.

Misalignment

Misalignment can cause concentrated wear on the bearings (Fig. 33). This angular loading will cause the excessive wear shown on one edge of the upper bearing and the opposite edge of the lower bearing. When this wear pattern is found, check the alignment of the shaft and bearings.

Tapered Bearing Journals

Tapered journals allow areas of excessive clearance between the journal and bearing; this distributes more wear on one edge of the bearing (Fig. 34). This wear is increased by the force on the bearing carrying the greater load.

Overheating

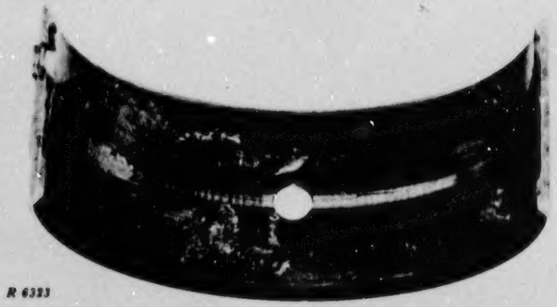


Fig. 35 — Bearing Fatigue Caused By Overloading And Heat

Overheating from overloads causes a metal fatigue which breaks away and voids the surface of the bearing (Fig. 35).

TROUBLE SHOOTING OF PLAIN BEARINGS

We have already discussed bearing failures by examining the bearing. Now let's learn about symptoms that indicate possible bearing failure. Some of the obvious signs are a sudden or sustained rise in temperature, excessive noise, rough operation, and excessive bearing and shaft clearance.

These Trouble Shooting charts are a general guide to help determine the possible cause and remedy of bearing failures.

Possible Causes	Symptoms			**Remedy**
	Excessive Temperatures	Excessive Noise and Rough Operation	Excessive Wear	
Shaft and bearing misaligned.	X	X	X	Realign.
Bearing caps too tight.	X		X	Retighten to specification or replace bearings with correct size.
Bearing overloaded.	X	X	X	Reduce load or speed.
Fatigue failure.	X	X		Replace bearing.
Faulty oil grooving.	X	X	X	Replace bearing.
Bearing surfaces too rough.	X	X		Complete break-in period or use suitable bearing.
Bearing clearances too small.	X	X		Replace with correct size bearing.
Unsuitable bearing materials because of poor fatigue resistance, conformability, embeddability, corrosion resistance, or thermal conductivity.	X	X		Replace with suitable bearing.
Faulty bearing design or construction.	X	X	X	Replace bearing.
Abrasive or corrosive contaminants in lubricant.	X	X	X	Replace lubricant.
Lubricant too light for imposed leads.	X	X	X	Use heavier lubricant.
Lubricant too heavy for bearing clearance.	X			Use lighter lubricant.
Lubricant too heavy for speed of rotation.	X			Use lighter lubricant.
Lubricant unsuitable for application.	X	X	X	Use recommended lubricant.
Oil passages blocked.	X	X	X	Clear oil passages.
Excessive vibration.		X	X	Eliminate cause of vibration.
Bearing cap loose.		X	X	Tighten to specification.
Excessive bearing clearance.		X		Replace with correct bearing.
Excessive leakage.		X	X	Replace seals.

Keep in mind that many of these symptoms can be present at once — and several causes can occur at the same time.

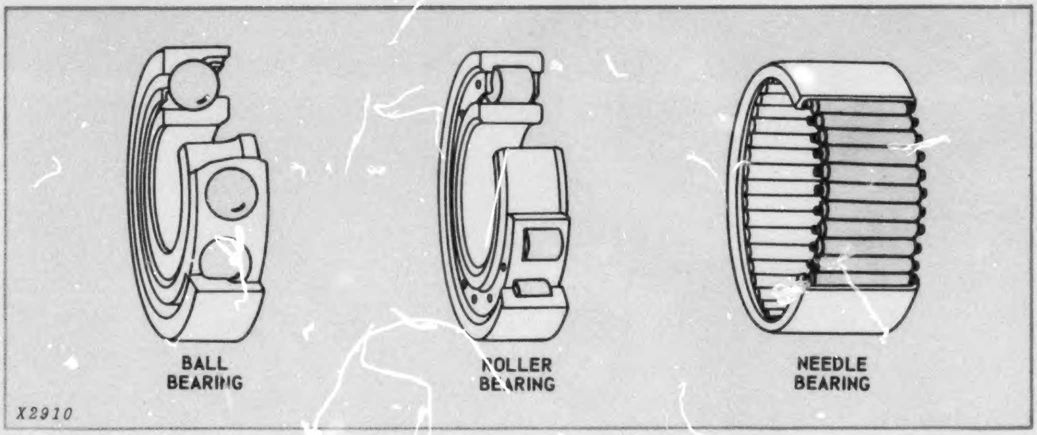

BALL
BEARING
ROLLER
BEARING
NEEDLE
BEARING
X2910

Fig. 36 — Three Basic Types Of Anti-Friction Bearings

ANTI-FRICTION BEARINGS

We are concerned with three basic types of anti-friction bearings (Fig. 36).

- **Ball bearings**
- **Roller bearings**
- **Needle bearings**

Most anti-friction bearings are made of hardened steel. However, some bearings are made of other materials, such as plastics.

BASIC PARTS

Most anti-friction bearings have similar parts:

1. *Two hardened-steel rings called* **races** *(Fig. 37).*

2. *Hardened-steel* **balls, rollers** *or* **needles** *which roll between the races.*

3. *Optional* **separators** *or cages (made of steel, bronze or plastic) which space the rolling elements around the races.*

On some bearings the outer or inner race is omitted and the rolling elements are in direct contact with the shaft or other mounting (as in many needle bearings).

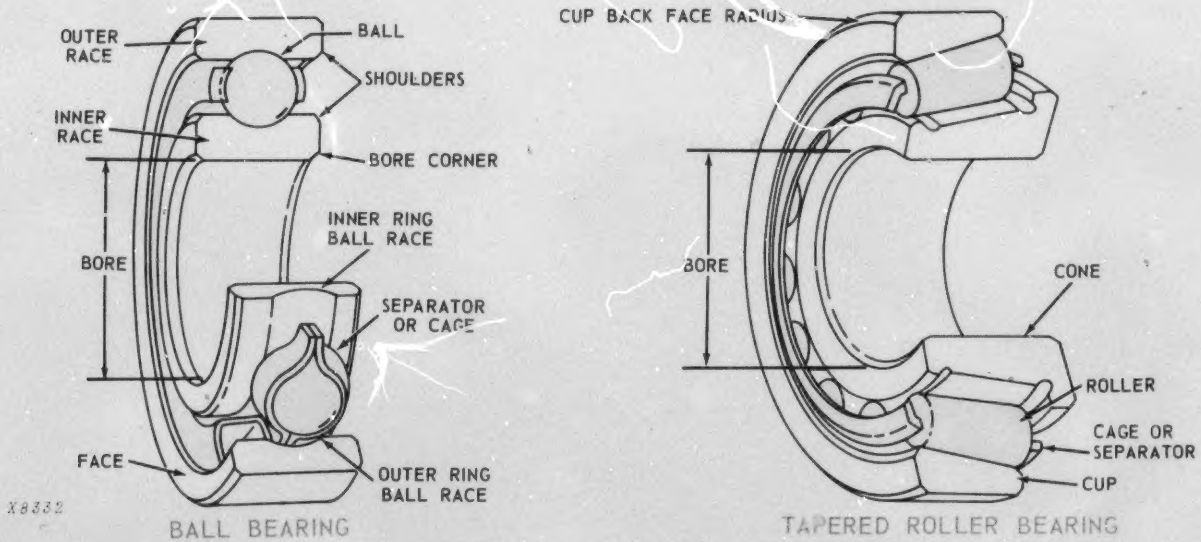

OUTER
RACE
BALL
SHOULDERS
INNER
RACE
BORE CORNER
INNER RING
BALL RACE
BORE
SEPARATOR
OR CAGE
FACE
OUTER RING
BALL RACE
X8332
BALL BEARING
CUP BACK FACE RADIUS
BORE
CONE
ROLLER
CAGE OR
SEPARATOR
CUP
TAPERED ROLLER BEARING

Fig. 37 — Basic Parts Of Anti-Friction Bearings

When two races are used, one race is normally pressed or fixed on a shaft or in a bore, while the other race is free to turn with the rolling elements. This is part of the "anti-friction" feature of these bearings.

We have already discussed the purposes, general types, advantages and disadvantages of all bearings in the introduction to this chapter. Before examining specific types of bearings, let's take a look at bearing capacities.

BEARING CAPACITIES

The load-carrying capacity of a bearing is determined by three conditions:

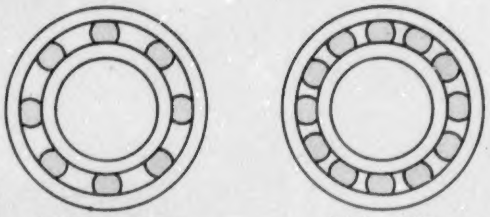
1. **Size of bearing.**
2. **Number of rolling elements.**
3. **Type of races.**

Some other factors, such as steel cleanliness and hardness, may also have an effect on bearing capacities.

Let's look at each factor.

Size Of Bearing

The size of a bearing is the primary factor which determines load-carrying capacity: A larger bearing will support more load than a smaller one of the same design.



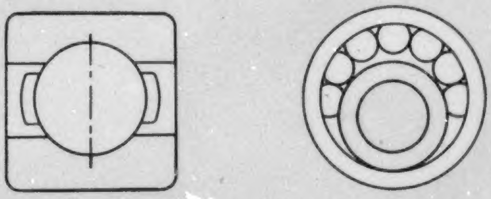
CONRAD TYPE– Fewer Rolling Elements

FULL TYPE– More Rolling Elements

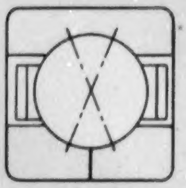
Fig. 38 — Number Of Rolling Elements

Number Of Rolling Elements

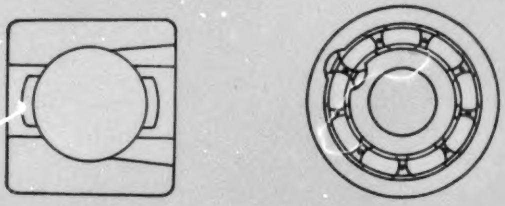
The *number of rolling elements* is also important. In Fig. 38 you can see that the Conrad-type ball bearing has fewer balls than the full-type bearing. The full-type bearing can support a greater radial load than the Conrad bearing. However, the Conrad bearing can withstand more thrust load than the full-type bearing. This is due to the race design, as you will see later. Often, the load capacity of a bearing is doubled by using a double row of balls or rollers.



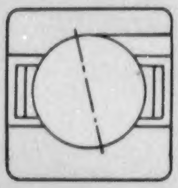
CONRAD BEARING. Inner Race In Eccentric Position for Loading. Good for Both Radial and Thrust Loads.



SPLIT RACE BEARING. Inner Race Is Center-Cut. Good For Thrust Loads Only.



FULL-TYPE BEARING. Has A Loading Slot. Holds More Balls, Only For Radial Loads.



ANGULAR-CONTACT BEARING. One Shoulder Of Outer Race Removed. Good For Thrust Loads – One Direction.

Fig. 39 — Types Of Ball Bearing Races

Types Of Bearing Races

The *type of races* in the bearing controls the load-carrying capacity, especially in ball bearings. Most roller and needle bearings have only two variations of races — split and continuous. Because of the load distribution of their rolling elements, these bearings are not affected greatly by the split race.

Ball bearings, on the other hand, have a variety of races. Basically, ball bearings have four race designs.

1. **Conrad Bearing**
2. **Full-Type Bearing**
3. **Split-Race Bearing**
4. **Angular-Contact Bearing**

It is important that a replacement bearing have the same load-carrying capacity as the original.

If, for example, you replace a Conrad bearing with a full-type bearing (Fig. 39) you will risk premature bearing failure.

The reason for this is that the *Conrad* bearing has a deep groove with continuous race shoulders. This gives it both good radial and thrust capacities. As you can see, the Conrad bearing is loaded with the inner race displaced. After loading, the inner race is moved back to center, the balls are evenly positioned, and the separators are installed.

The *full-type* bearing has a loading slot which allows more balls to be installed than can be loaded in the Conrad bearing. Because of this loading slot, the full-type bearing cannot take the thrust loads which the Conrad bearing can. For this reason, the full-type bearing is recommended where only radial loads are present.

Split-race bearings (either inner or outer race) are essentially angular-contact bearings that can take high thrust loads in either direction. This is because of their high shoulders and the ability to load a full complement of balls because of the removable split races. These bearings cannot accept high radial loads.

The *angular-contact* bearing (Fig. 39) can accept both radial and thrust loads — but thrust loads in one direction only. However, it cannot withstand as much radial load as the Conrad bearing.

TYPES OF BALL BEARINGS

Various types of ball bearings are designed to carry different loads. Sizes range from fractions of an inch to several inches in diameter.

Since a given bearing is used for a specific job, such as a radial load, it must not be subjected to thrust loads or it will fail prematurely.

Another thing to keep in mind is that ball bearings are precision made and finely finished. They must be handled with care and kept clean.

Notice in Fig. 40 that the center lines of force and the areas of contact are shown for each bearing.

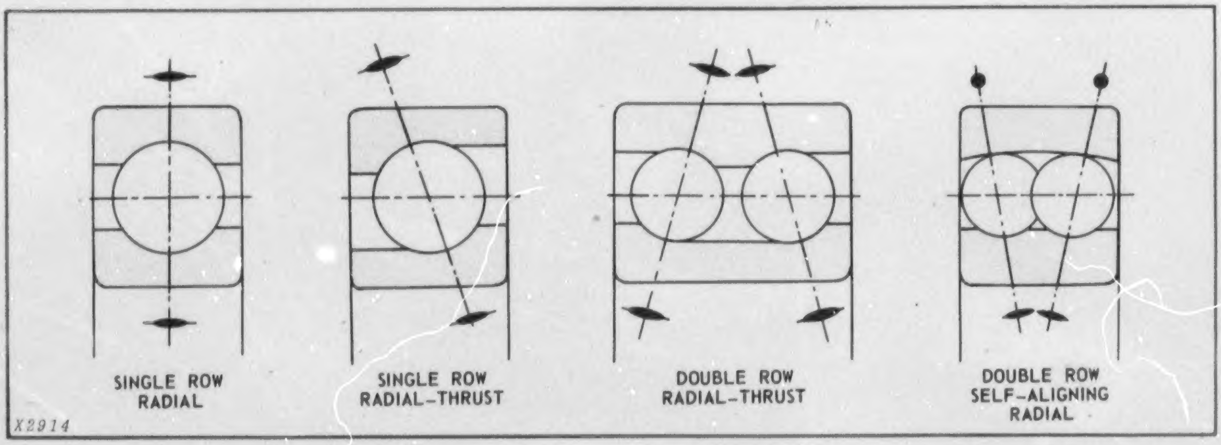


Fig. 40 — Types Of Ball Bearings

The four basic designs of ball bearings are:

1. **Radial-Load**
2. **Radial- and Thrust-Load**
3. **Self-Aligning, Radial-Load**
4. **Thrust-Load**

Radial-load ball bearings are available as either single row or double row (Fig. 40). Some have shields that prevent foreign matter from entering the bearing and seals that retain the lubricant and exclude dust. Though these bearings primarily support radial loads, they will accept some thrust loads, providing the load is not too great. The grooves of radial bearings are shallow with little shoulder to support thrust loads.

Radial- and thrust-load ball bearings are also available as singles or doubles (used in pairs or double rows), and they also have optional shields and seals available. As singles, these bearings will support radial loads and thrust loads in one direction — against the higher shoulder of the outer race (Fig. 40). When singles are combined into duplexes, they can take thrust loads in either direction, as can the double-row design.

Self-aligning radial-load ball bearings can be either internally self-aligning or externally self-aligning. They can accept either *initial* misalignment (by having a spherical outer race) or they can accept *running* misalignment (by having a spherical roller path). The first type is usually a sealed bearing. Fig. 40 shows the internally self-aligning bearing.

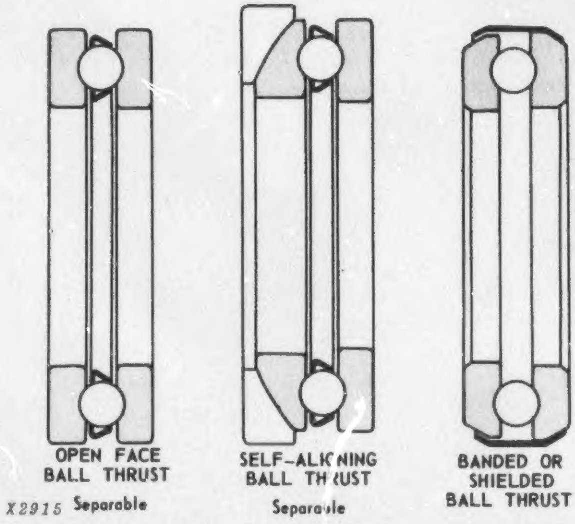

OPEN FACE
BALL THRUST
X2915
Separable
SELF-ALIGNING
BALL THRUST
Separable
BANDED OR
SHIELDED
BALL THRUST

Fig. 41 — Thrust-Load Ball Bearings

Thrust-load ball bearings (Fig. 41) are usually single row and may have a shield or seal. These bearings will accept full thrust loads and some light radial loads. They are usually used in conjunction with radial-load bearings. In Fig. 41 you can see that three varieties are available. The open-face and self-aligning designs are separable, but the shielded is not.

TYPES OF ROLLER BEARINGS

Where great loads are present, roller bearings are used instead of ball bearings.

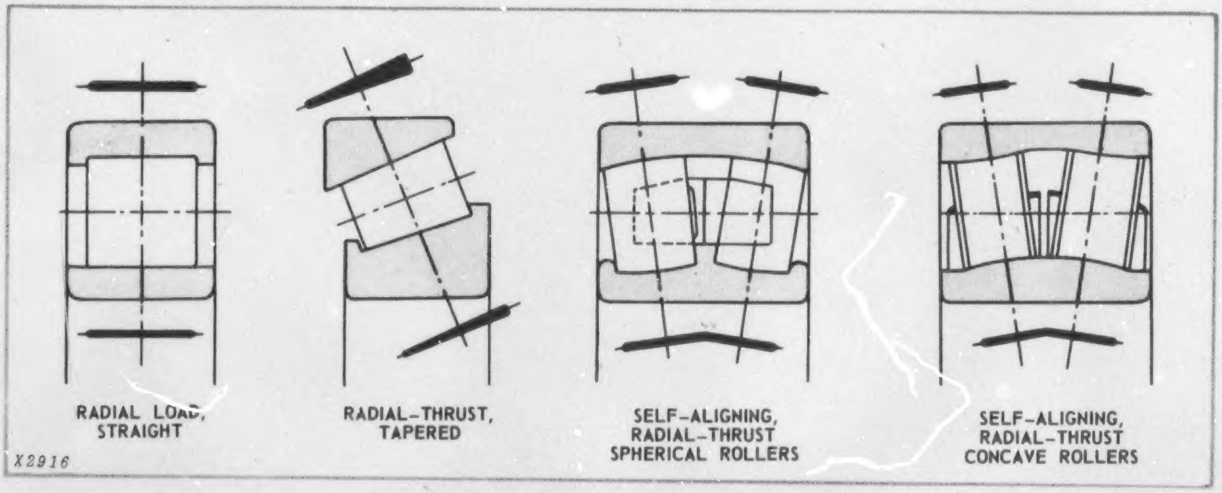

RADIAL LOAD,
STRAIGHT
RADIAL-THRUST,
TAPERED
SELF-ALIGNING,
RADIAL-THRUST
SPHERICAL ROLLERS
SELF-ALIGNING,
RADIAL-THRUST
CONCAVE ROLLERS
X2916

Fig. 42 — Basic Types Of Roller Bearings

Roller bearings are also designed for loads and applications similar to those of ball bearings. As with ball bearings, roller bearings are precision-made and must be handled with care and kept clean.

Notice in Fig. 42 that the center lines of force and the areas of contact are shown for each bearing.

The five basic types of roller bearings are:

1. **Radial-load, straight roller**
2. **Radial- and thrust-load, tapered roller**
3. **Self-aligning, radial- and thrust-load, spherical roller**
4. **Self-aligning, radial- and thrust-load, concave roller**
5. **Thrust-load**

Radial-load, straight roller bearings have high radial capacity, but they cannot accept much misalignment or thrust loads (Fig. 42). They are also available with two or more rows of rollers. Some are non-separable while others have separable inner or outer rings. When high speeds and heavy loads are imposed, these bearings are normally used.

Radial- and thrust-load, tapered roller bearings will accept combined heavy radial and thrust loads (Fig. 42). They are normally used in pairs or double-row units for moderate and low speeds. These are the most popular types of roller bearing. They are adjustable through their separable outer cups or through their cones. Some double-row units are pre-adjusted.

Self-aligning, radial- and thrust-load, spherical roller bearings (Fig. 42) have great load carrying capacity due to the number, size, and shape of the rollers and the spherical aligning surface. Because these bearings are self-aligning, some misalignment will not affect their performance. These bearings can accept more thrust loads than straight rollers, but less thrust than tapered rollers. The single row, radial bearing cannot accept much thrust load. The single row, radial and thrust bearings can only accept thrust loads in one direction. The double row bearing, however, can withstand thrust loads in either direction. Obviously this bearing offers more versatility than any other roller bearing — which is important when a bearing must function under a variety of conditions.

Self-aligning, radial- and thrust-load, concave roller bearings (Fig. 42) have the same load-carrying characteristics as the spherical roller bearings. The basic differences are that the rollers are concave rather than convex, and the spherical self-aligning surface is on the *inner* ring rather than on the outer.

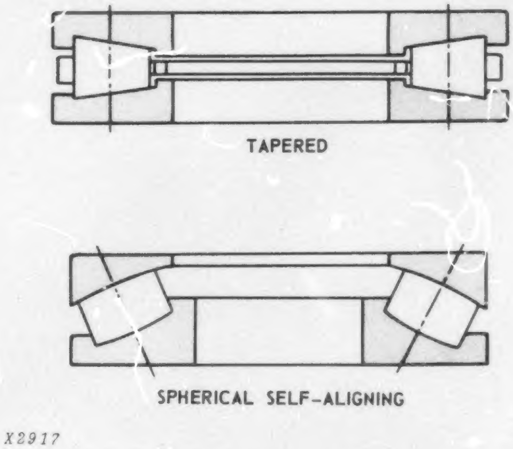


Fig. 43 — Thrust-Load Roller Bearings

Thrust-load roller bearings (Fig. 43) can carry heavy thrust loads, but they cannot withstand any radial loads. The *tapered* roller bearing (top) cannot accept misalignment as can the *spherical* self-aligning roller bearing (bottom). Normally, thrust-load roller bearings are used in conjunction with radial load bearings.

TYPES OF NEEDLE BEARINGS

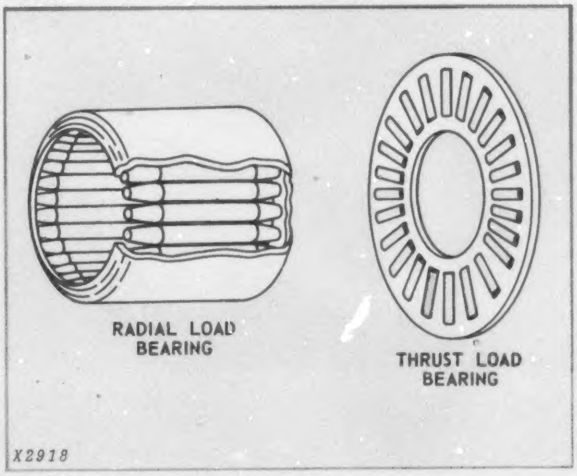


Fig. 44 — Basic Types Of Needle Bearings

Needle bearings have very small diameter rollers or needles, but high load-carrying capacity (Fig. 44). They are most often used where space is limited, but they do not perform at high speeds as well as roller or ball bearings. Also, they will not tolerate much misalignment.

There are two main types of needle bearings:

- **Radial-load bearings**
- **Thrust-load bearings**

The *radial-load needle bearing* (Fig. 44) may or may not have an inner sleeve or race. The *thrust-load bearing* can be used with or without races. If used without races, the mating surfaces must be ground square and hardened. The needles may be either caged, retained by grease, or loose for hand assembly.

MOUNTINGS FOR ANTI-FRICTION BEARINGS

Anti-friction bearings must be mounted so that their shape is not distorted, the rolling elements are not bound, and the inner and outer races are

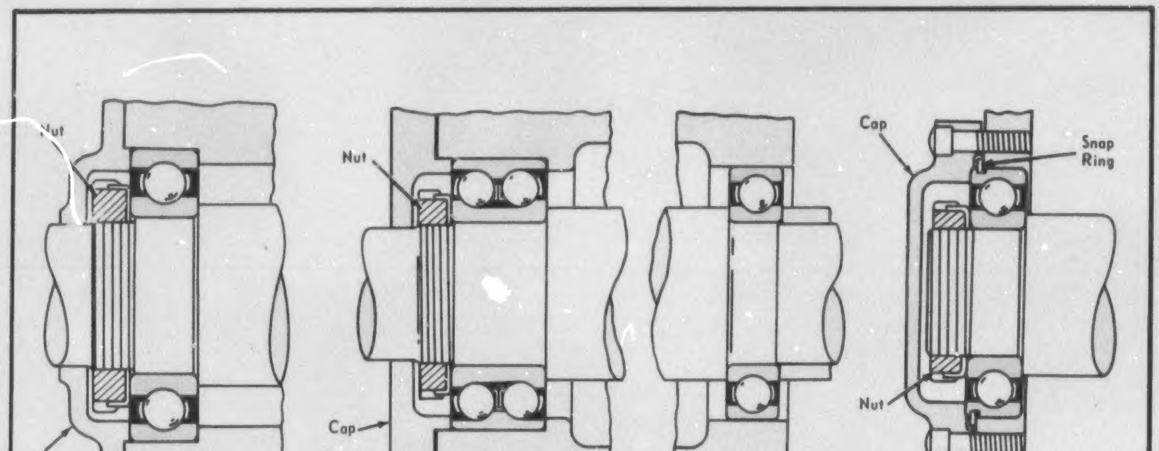

Nut
Cap
① SINGLE ROW RADIAL
Nut
Cap
② DOUBLE ROW RADIAL-THRUST
③ SINGLE ROW "FLOATED"
Cap
Snap Ring
Nut
④ SINGLE ROW SNAP RING
Nut
⑤ RADIAL-THRUST
Arm
⑥ THRUST
⑦ INTERNALLY SELF-ALIGNING
Flanges
Set Screw
Locking Collar
⑧ EXTERNALLY SELF-ALIGNING
X2919

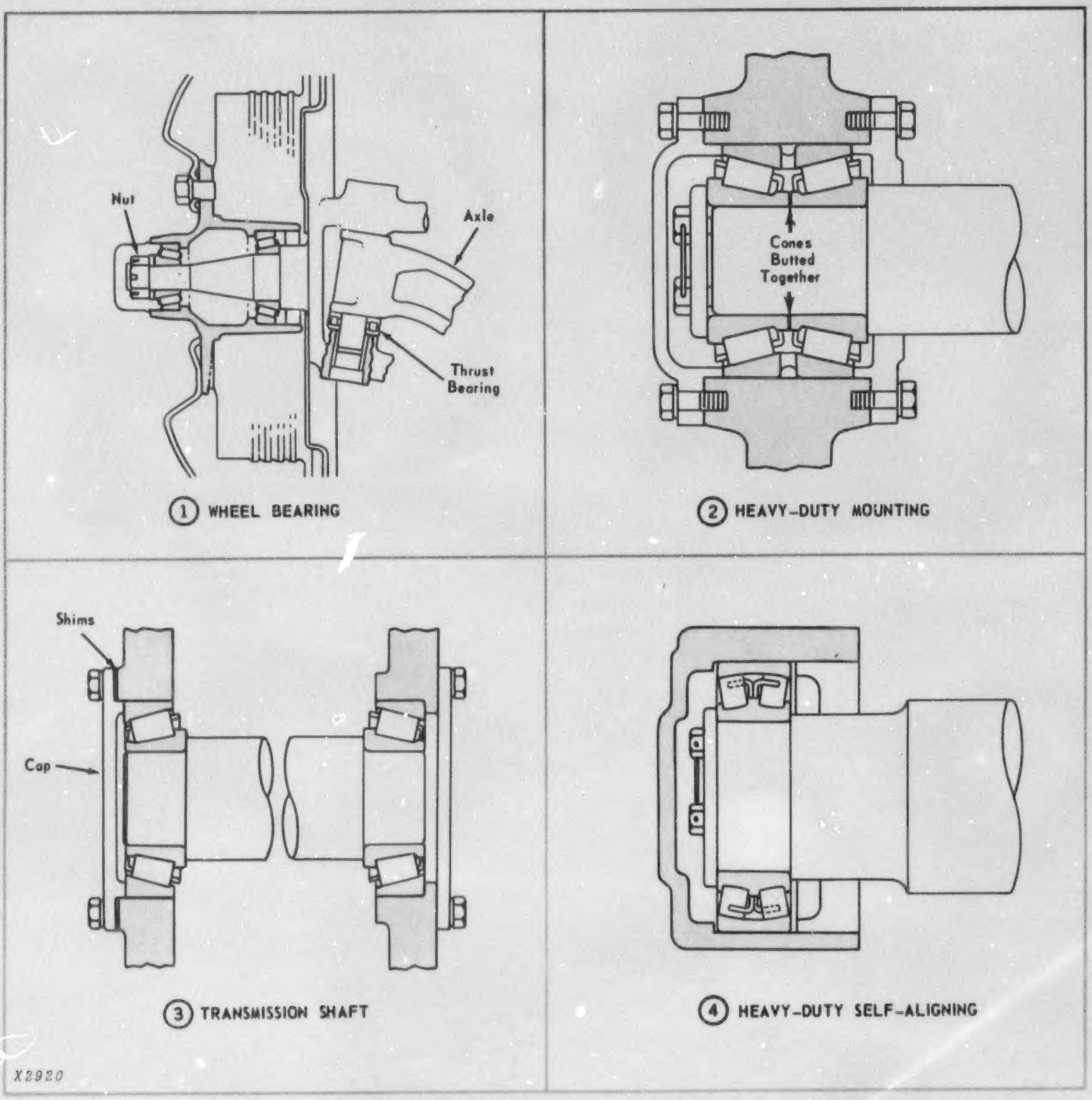
Fig. 45 — Typical Ball Bearing Mountings

aligned (not necessary with self-aligning bearings). In addition when two or more bearings are mounted on a common shaft, the axis of each bearing must be aligned with the other.

Many anti-friction bearings have seals to retain lubricant and exclude dirt. Anti-friction bearings may also be lifetime lubricated and sealed on both sides. See the section on "Seals" later in this manual.

Anti-friction bearings are usually mounted with one race a push fit and the other a press fit. A push fit means that the bearing race can be slid into place by hand. A press fit requires a press or a driver to install the race.

Remember that normally the press-fit race is pressed onto or into the *rotating* part, and the push-fit race is pushed onto or into the *stationary* part. However, this rule-of-thumb is not true in every situation. Where large bearings encounter tremendous loads and speeds, *both* races may be *pressed* into place. These bearings must have special internal clearances built in.



① WHEEL BEARING

② HEAVY-DUTY MOUNTING

③ TRANSMISSION SHAFT

④ HEAVY-DUTY SELF-ALIGNING

Fig. 46 — Typical Roller Bearing Mountings

Ball Bearing Mountings

A typical method of mounting a single row, radial bearing (1) is shown at upper left in Fig. 45. The bearing is held in position against the shoulders by the nut and cap.

The double row, radial-thrust bearing (2) is mounted similarly (Fig. 45, page 23), but great importance is placed on preventing movement due to the thrust loads that may be imposed upon it.

Often, the other end of the shaft has a single or double row, "floated" bearing (3, Fig. 45). This bearing is allowed to shift in the bore rather than accept thrust loads — hence the description "floated."

When the bore must be straight through (without shoulders), a snap ring is often used (as shown in 4, Fig. 45) to retain the bearing in position.

Radial-thrust bearings (5) are most often mounted in wheels as shown. The outer race is pressed into the bore and the inner race is a push fit. Adjustment is made with the nut.

Thrust bearings (6) are mounted as shown for clutch disengagement. The arm disengages the clutch because of pressure applied through the bearing.

Internally self-aligning bearings (7) may be mounted as a "floating" bearing, as shown, or they may be retained by a nut and cap.

The externally, self-aligning bearing (8), is often mounted with flanged retainers as shown. Similar bearings may be mounted in a spherically-machined housing. A locking collar is used to secure the bearing. (The collar must always be tightened in the direction of shaft rotation, then locked with a set screw.)

Roller Bearing Mountings

One of the most common methods of mounting tapered roller bearings is shown in Fig. 46, No. 1. Typical wheel bearings are shown. The outer race or cup is pressed into the housing and the inner race or cone is pushed onto the shaft. Adjustment is made by turning the nut.

Also shown in Fig. 46, No. 1 is a thrust bearing. In this case the thrust bearing is used to support the load of the axle.

In heavy-duty applications, double roller bearings are used (No. 2). Here the outer race or cup is one-piece and the cones are two singles.

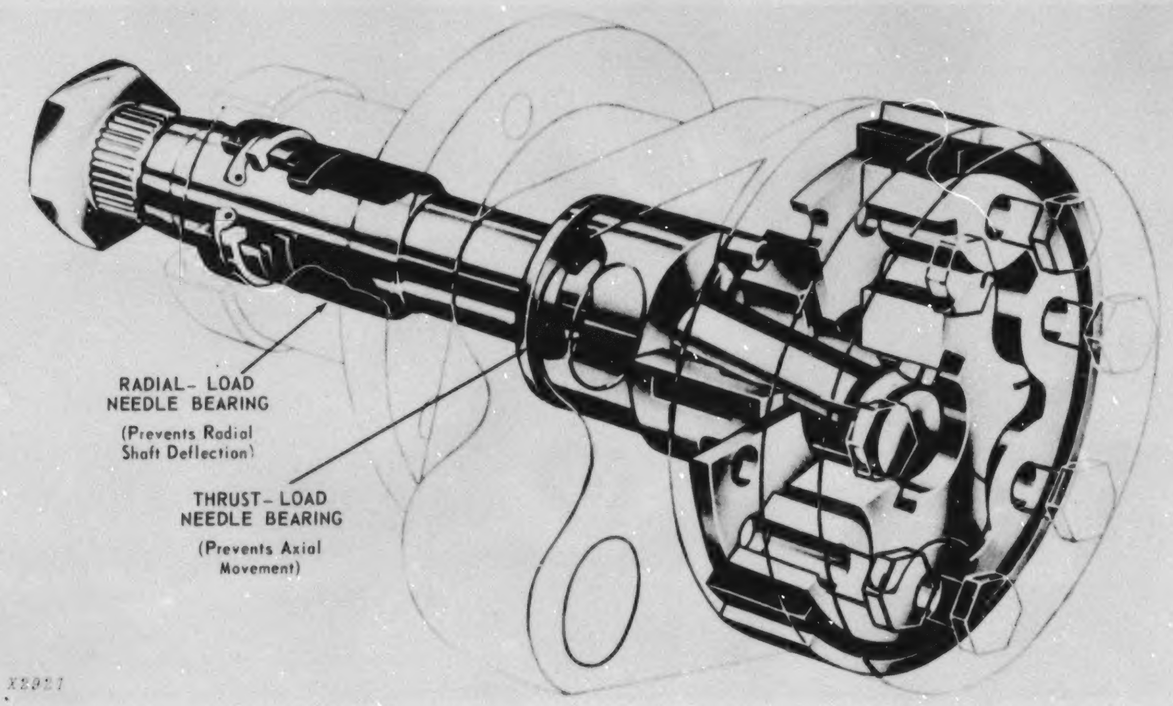

RADIAL- LOAD NEEDLE BEARING
(Prevents Radial Shaft Deflection)
THRUST- LOAD NEEDLE BEARING
(Prevents Axial Movement)
X2927

Fig. 47 — Typical Needle Bearing Mountings

This bearing is pre-adjusted by butting the cones together (spacers can also be used.) Another common mounting method is used in transmissions (No. 3). The transmission shaft is supported at both ends by tapered roller bearings as shown. Adjustment is made by using shims, as necessary, under the cap.

One type of mounting for heavy-duty self-aligning bearings is shown in Fig. 46, No. 4. This bearing and mounting is used where heavy loads are encountered and alignment is a problem.

Needle Bearing Mountings

Two types of needle bearings are shown mounted in the hydraulic steering pump in Fig. 47.

The radial-load bearing accepts radial loads and prevents shaft deflection, while the thrust-load bearing prevents axial movement of the shaft.

Another common use of radial-load needle bearings is in universal joints where space and weight is at a premium and loads are high.

In some needle bearings, the needles must be assembled by hand during installation. The needles may be packed in heavy grease, retained by rubber bands, or by an adhesive strip until the bearing is in place. Be careful not to lose any needles.

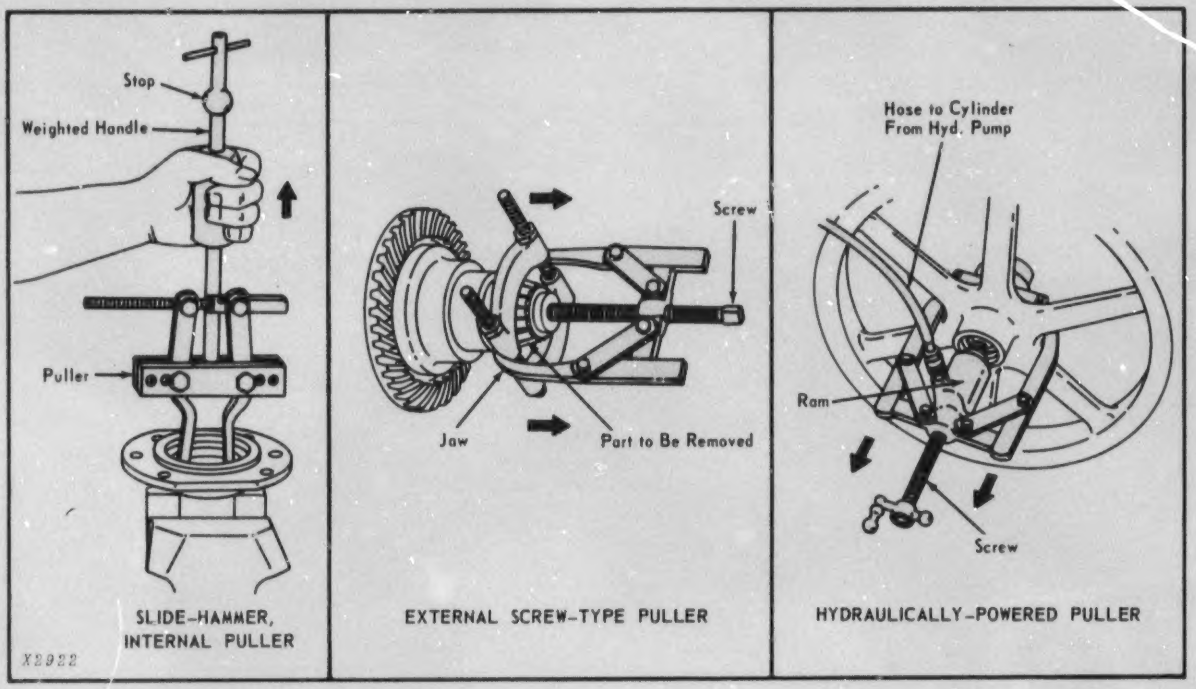
TIPS FOR ANTIFRICTION BEARING MAINTENANCE

Do

1. *Do work with clean approved tools, in clean surroundings.*
2. *Do clean outside of housings before exposing bearings.*
3. *Do handle bearings with clean, dry hands, or better, use clean canvas gloves.*
4. *Do work on a metal or metal covered bench.*
5. *Do treat a used bearing as carefully as a new one, until the used one is proven to be defective.*
6. *Do use clean solvents and flushing oils.*
7. *Do lay bearings out on a clean surface.*
8. *Do protect disassembled bearings from dirt and moisture.*
9. *Do wipe bearings, if necessary,* **only** *with clean, lint-free rags.*
10. *Do keep bearings wrapped in oil-proof paper when not in use.*
11. *Do thoroughly clean the inside of housings before installing bearings.*
12. *Do install new bearings as they come from the package, without washing, if they are received in a sealed container.*
13. *Do keep lubricants clean when applying them, and cover the containers when not in use.*

Don't

1. *Don't use wooden mallets.*
2. *Don't handle bearings with dirty or moist hands.*
3. *Don't spin uncleaned or dry bearings.*
4. *Don't spin* **any** *bearing with compressed air.*
5. *Don't use the same container for both cleaning and final rinse of used bearings.*
6. *Don't use cotton waste or dirty rags to wipe bearings.*
7. *Don't scratch or nick bearing surfaces.*
8. *Don't use gasolines containing tetraethyl lead, as the fumes may be injurious to health, as well as a fire hazard.*
9. *Don't use incorrect type or amount of lubricant.*


Stop
Weighted Handle
Puller
X2922
Screw
Jaw
Part to Be Removed
Hose to Cylinder
From Hyd. Pump
Ram
Screw

SLIDE-HAMMER, INTERNAL PULLER

EXTERNAL SCREW-TYPE PULLER

HYDRAULICALLY-POWERED PULLER

Fig. 48 — Typical Bearing Pullers

MAINTENANCE OF ANTI-FRICTION BEARINGS

The most important factor for long bearing life is good bearing maintenance. This includes proper lubrication, repair, diagnosis of failures, installation, and adjustment. Some of the key "do's" and "don'ts" are shown on page 26.

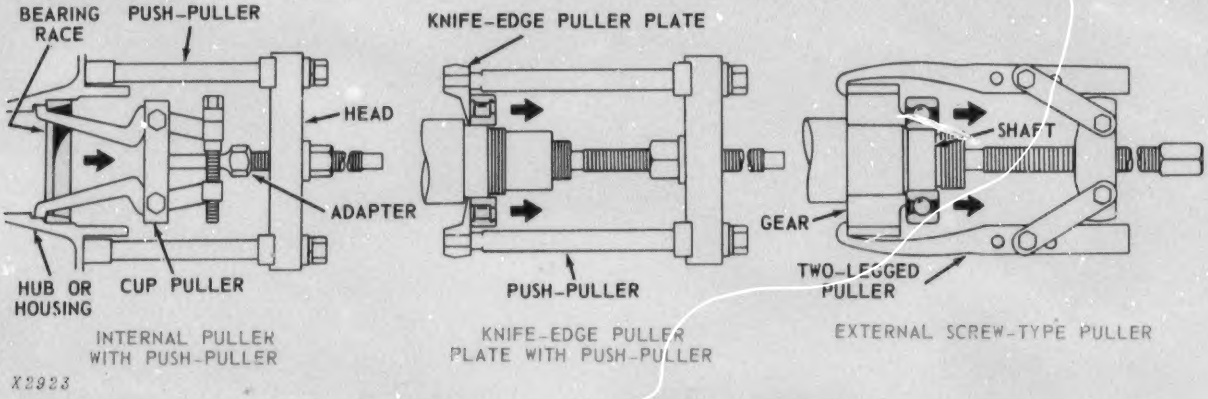
Let's examine bearing maintenance, starting with bearing removal.

Removal Of Bearings

Before attempting to remove any bearing, clean the bearing housing and shaft. Consult the Technical Manual or Service Manual for removal procedures. If no procedures are given, study the bearing mounting carefully to determine how it must be removed. The maintenance tips on the preceeding page are important when working with bearings.

Bearings can be removed by three basic methods:

1. *Using either mechanical or hydraulic pullers*
2. *Using either mechanical or hydraulic presses*
3. *Using a hammer and proper driver*


BEARING RACE
PUSH-PULLER
HEAD
ADAPTER
HUB OR HOUSING
CUP PULLER
KNIFE-EDGE PULLER PLATE
PUSH-PULLER
SHAFT
GEAR
TWO-LEGGED PULLER
X2923

INTERNAL PULLER WITH PUSH-PULLER

KNIFE-EDGE PULLER PLATE WITH PUSH-PULLER

EXTERNAL SCREW-TYPE PULLER

Fig. 49 — Correct Puller Applications

REMOVING BEARINGS USING PULLERS

Three types of bearing pullers are shown in Fig. 48. The *slide-hammer puller* is shown in the first drawing. By sliding the weighted handle against the stop, the bearing is forced out of the housing.

Another type of puller is the *screw-type puller* which pulls the bearing from the shaft by the force of the screw turning.

The *hydraulically powered puller* is the most powerful. Some models of hydraulic pullers are capable of several tons of force.

Pullers may be for either internal or external applications, depending on the need. Some pullers can be used for both jobs because they have reversible jaws with both external and internal ends.

Fig. 49 illustrates some common puller applications. The first puller shown is an *internal* type used with a push-puller. The push-puller may also be used for installation, as we will see later. The legs of the push-puller support the head while the screw is turned, pulling the bearing cup from the housing.

A *knife-edge puller* plate is available to remove bearings where other pullers would damage the bearing. This plate is shown at center in Fig. 49 removing a bearing from a shouldered shaft. If the regular external-type puller were used to remove this bearing, the force exerted on the outer race would damage the bearing. Notice that the knife-edge plate is used with a push-puller; the external screw-type puller can also be used with the knife-edge plate.

The *external screw-type* puller can be used to remove bearings as shown at right in Fig. 49 provided there is some solid object which allows the jaws of the puller to force the bearing off.

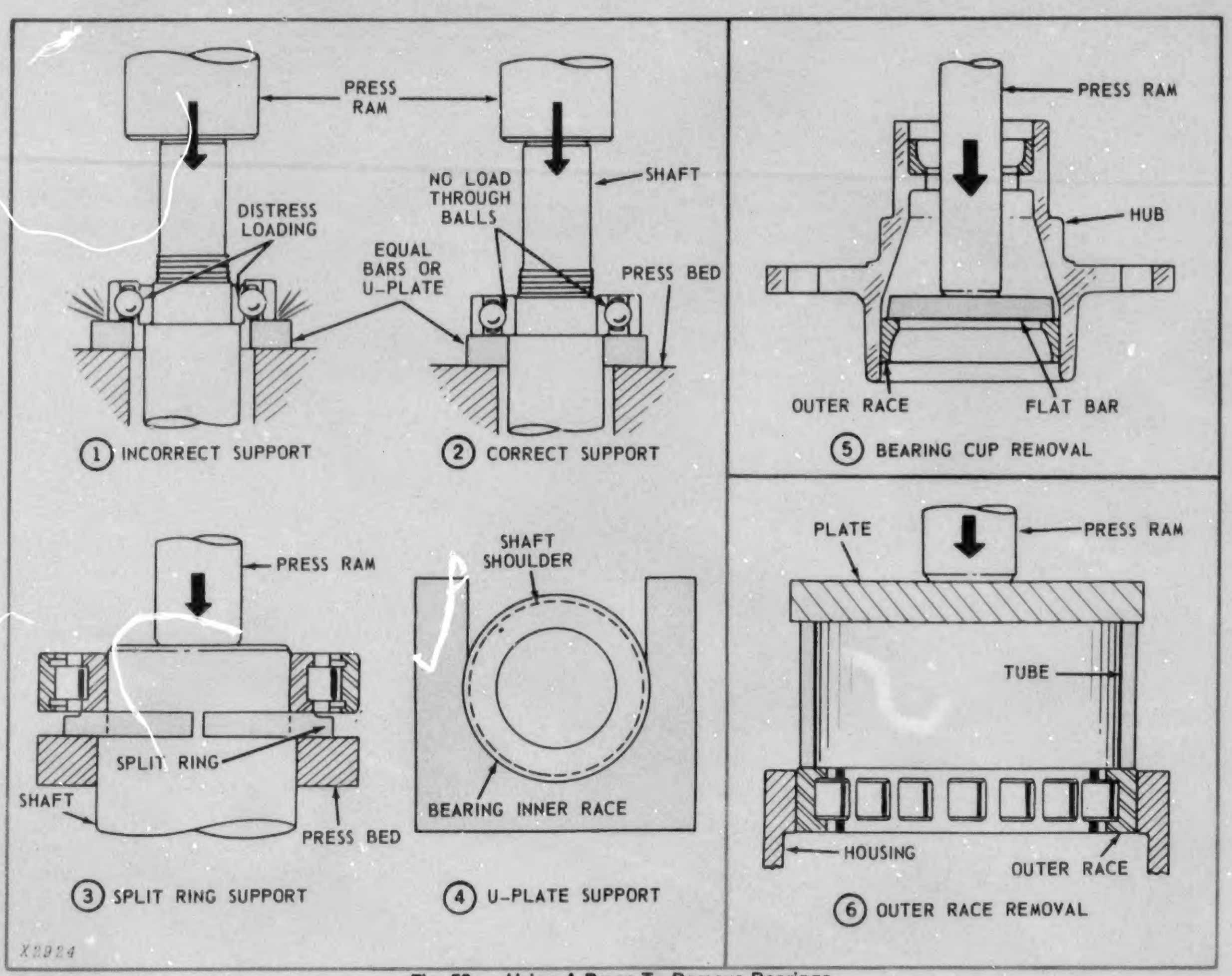
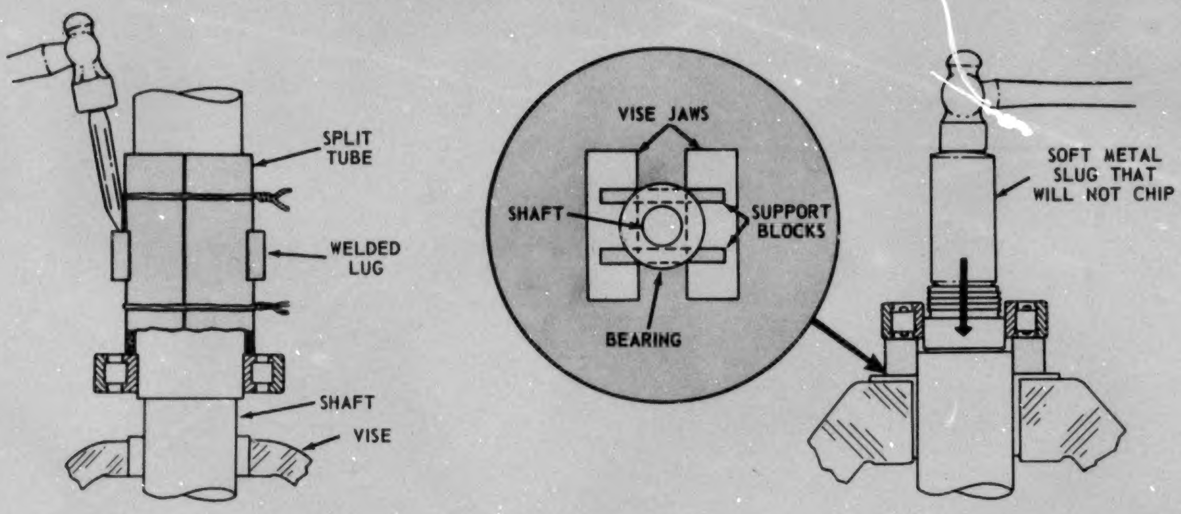

PRESS RAM
DISTRESS LOADING
NO LOAD THROUGH BALLS
SHAFT
EQUAL BARS OR U-PLATE
PRESS BED
① INCORRECT SUPPORT
② CORRECT SUPPORT
PRESS RAM
HUB
OUTER RACE
FLAT BAR
⑤ BEARING CUP REMOVAL
PRESS RAM
SPLIT RING
SHAFT
PRESS BED
③ SPLIT RING SUPPORT
SHAFT SHOULDER
BEARING INNER RACE
④ U-PLATE SUPPORT
PLATE
PRESS RAM
TUBE
HOUSING
OUTER RACE
⑥ OUTER RACE REMOVAL
X2924

Fig. 50 — Using A Press To Remove Bearings



USING TUBE FOR REMOVAL

USING VISE AND SUPPORT BLOCKS

Fig. 51 — Correct Methods Of Removing Bearings With A Hammer

Many variations of these basic pullers are available in several sizes and capacities. Pullers are one of the best tools to use to remove bearings easily and safely and to avoid damage to the bearing or its mating part.

REMOVING BEARINGS USING A PRESS

Another excellent tool for removing bearings correctly is the press. Either a mechanical or hydraulic press can make bearing removal easy. *Avoid excessive force.*

When removing a bearing from a shaft, be sure that the inner race is supported so that the outer race is not distress loaded. If force is transmitted through the outer race, damage may result to the bearing.

In Fig. 50 various methods of removing bearings with a press are shown.

In example, No. 1, *incorrect* support of the inner race is shown. This forces the balls against the shoulders of the bearing races — which could result in chipping or cracking of the races or balls. Example No. 2 shows the *correct* support of the inner race. Split rings (3) or U-plates (4) are also available to provide correct support.

Bearing cups (5) may be pressed from the housing using a flat bar which transmits ram pressure. This can only be used when the housing is open from the opposite side and the press has enough clearance to accept the housing.

To press the outer race from a housing (6), use a tube that is slightly smaller in diameter than the outer race. Place a plate over the tube and press the bearing from the housing.

REMOVING BEARINGS USING HAMMERS AND DRIVERS

If a bearing puller or a press is not available, the bearing can be removed with a hammer and a driver. In Fig. 51 you can see two methods for removing bearings from a shaft.

The illustration at left shows the use of a tube placed over the shaft to drive the bearing from the shaft. If the shaft has obstructions, the tube may be split and fastened to the shaft as shown. The welded lugs on the side of the tube provide a surface to strike with the hammer and punch.

The other method, shown at right in Fig. 51, is similar to what we described for presses. Use support blocks, split rings, or a U-plate to support the inner race of the bearing. Then drive the shaft from the bearing with a soft slug or driver.

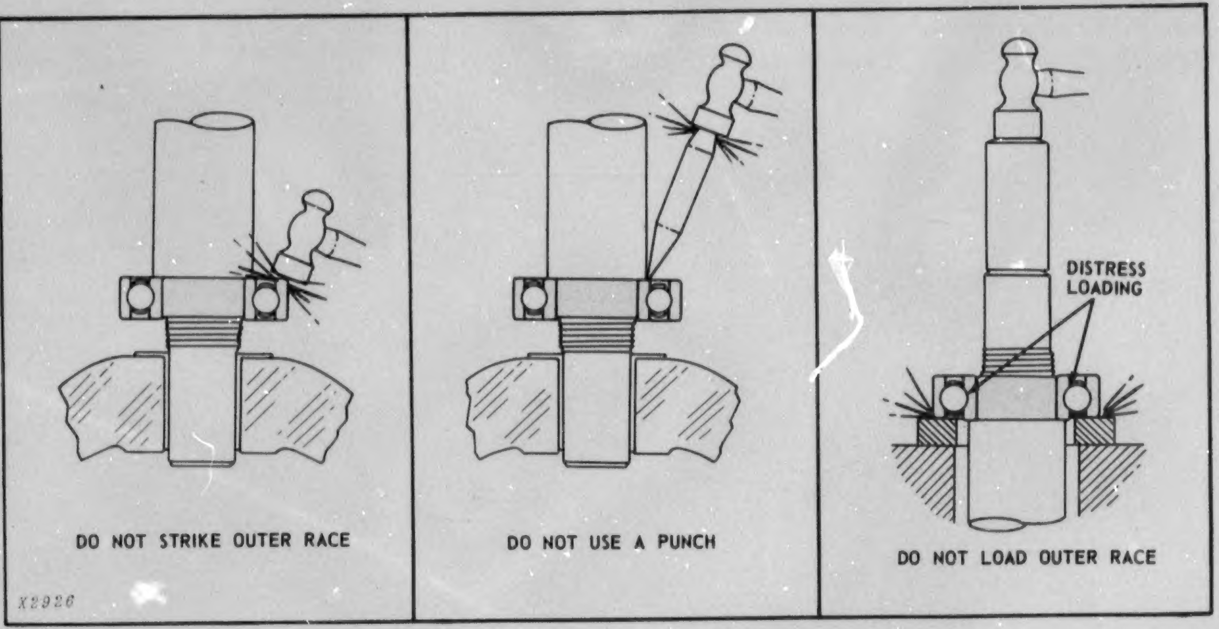


Fig. 52 — Incorrect Methods Of Removing Bearings With A Hammer

The three *incorrect* methods of removing bearings shown in Fig. 52 will probably result in bearing damage:

1. Do not strike the outer race — the races or balls will chip or crack.

2. Do not use a punch as shown; it may slip and damage the balls or races.

3. Do not load the outer race. Be sure that the supports are under the inner race or damage will result.

Cleaning And Inspection Of Bearings

After removal, bearings must be cleaned before inspection. If the bearing is sealed and does not have removable shields, it cannot be cleaned. These bearings can be checked only for external damage or for smooth turning. Bearings with a shield on one side only can be cleaned and inspected just as those without shields.

Always follow the manufacturer's recommendations for cleaning bearings. Use only petroleum solvents that are recommended for washing. Other solvents may be used, such as kerosene, naptha, etc., but they may not be as safe nor clean as well as solvents formulated for washing purposes. Most all solvents are very flammable and precautions must be taken to prevent fire. Also, many solvents are poisonous when inhaled or absorbed into the skin.

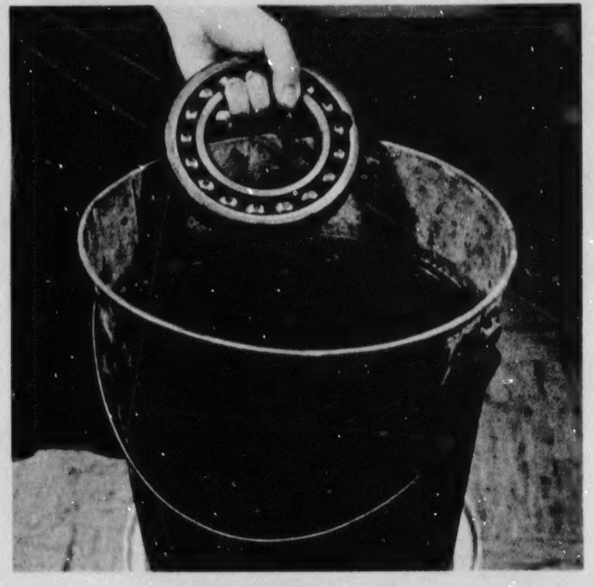


Fig. 53 — Cleaning Bearings In A Container Of Safe Solvent

Do not try to clean bearings in a container barely big enough to hold them. The container must be big enough to permit the bearing to be sloshed around without touching the bottom where the dirt settles (Fig. 53). Never allow the bearings to touch bottom or they will be contaminated with dirt recently washed off.

Soak the bearings long enough to loosen the grease and dirt — several hours or overnight. Use a short-bristled brush that will not lose its bristles or break off. After all visible dirt is removed, rinse the bearing in a container of *clean* solvent and then dip the bearing in oil.

If bearings may be reinstalled, inspect them carefully. When some doubt exists whether or not to replace the bearing, use this reasoning — if frequent inspections are given and the bearing is easy to replace, then the risk of failure may not be so great; however, if infrequent inspections take place and the bearing is difficult to remove and install, then the doubtful part should be replaced with a new one.

If the bearings have seals or shields, also inspect them for damage and wear. If the seals are not removable and they are damaged or worn, the whole bearing must be replaced. Be sure to replace those seals that are replaceable if they are defective. Worn or damaged seals will allow dirt and moisture to enter the bearing and shorten bearing life.

Visually inspect the exterior of the bearing for cracks in the races, dented seals, and broken or damaged separators, balls, or rollers. If the bearing has been overheated, it will be a brownish blue or bluish black color. If any of these signs are found, the bearing should be replaced.

Inspect separable bearings for pitted, scratched, or flaked balls, rollers, or races. Replace the bearing if any of these signs of damage are found.

The inner surfaces and rolling elements in a suspected non-separable bearing may be examined by shining a flashlight or reflected light from a strong light source between balls or rollers. Any visible pits or scratches are signs of damage and the bearing should be replaced.

Inspect outer race for proper wear pattern to assure no end loading or "tipping" has occurred.

If no visual signs of damage and wear are present, hold the bearing (Fig. 54) and rotate the outer race *slowly. Never spin it*. If any clicking or sticking is found, reclean the bearing. If after cleaning the condition still exists, replace the bearing.

Thrust bearings or tapered roller bearings can be inspected in the same way, except place the bearing on a clean surface and lightly apply hand pressure and rotate the bearing as shown at right in Fig. 54.

If the bearings are not to be reinstalled at once, wrap them in a clean, oil-proof paper, place in a clean box and store in a dry, dust-free place.

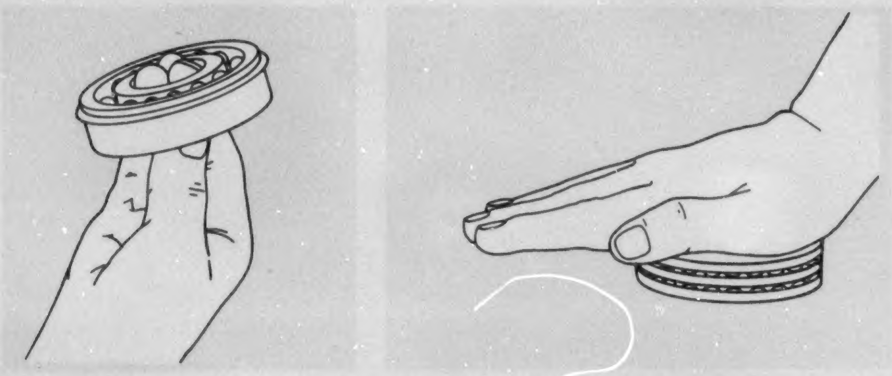
When bearings are found to be damaged, the cause must be determined or it may occur again when the new bearing is installed. This brings us to diagnosis of failures.

DIAGNOSIS OF FAILURES

Failures of anti-friction bearings may be caused by several things, but keep in mind that properly maintained bearings do not wear out — they eventually fail due to fatigue. Bearings which fail for reasons other than *normal* material fatigue are considered to be premature failures.

Fatigue Failures

The first indications of *fatigue failure* may be noisy running and increased vibration. Upon examination of the bearing races you will find that the metal surfaces of the races have flaked away as shown in Fig. 55. This flaking is caused by the effects of speed and load.



STRAIGHT BEARING – ROTATE OUTER RACE SLOWLY

THRUST BEARING – ROTATE BY LIGHT HAND PRESSURE

X2928

Fig. 54 — Inspecting Bearings

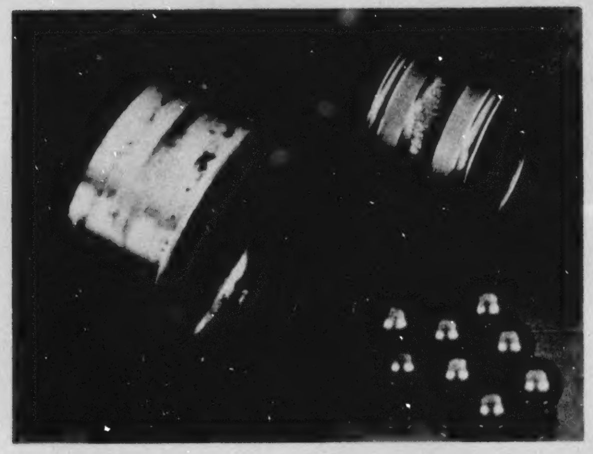


Fig. 55 — Fatigue Failure Of Bearing

Decrease in speed or load will extend bearing life — conversely, an increase in speed and load will shorten the bearing life. This is why it is important to use the correct bearing for this job — otherwise, premature, fatigue failure may occur.

Premature Failures

Premature failures are usually the result of one or more of the following causes:

1. *Contamination*
2. *Distortion*
3. *Misalignment*
4. *Improper fitting*
5. *Improper lubrication*
6. *Vibration while bearing is stationary*
7. *Electrical current passing through bearing*
8. *Defects in material*
9. *Improper servicing techniques*

NOTE: Since ball, roller, and needle bearings are subject to similar failures that have the same causes and effects, the following illustrations will show examples of typical failures rather than specific failures for each type of bearing.

Contamination

Contamination in a bearing is any foreign matter that will cause damage to the bearing. Moisture and any type of abrasive, such as dirt or sand will cause premature failure of the bearing.

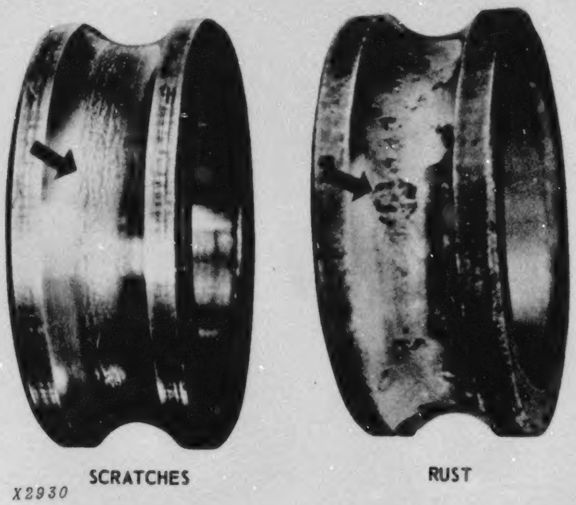


Fig. 56 — Contamination Caused This Damage

Fig. 56 shows damage caused to bearing races by abrasive contaminants and moisture. The abrasives scratched and scored the race. Moisture caused the other bearing race to rust. Both types of damage, of course, cause premature failure. This type of damage may be prevented by using the correct lubricant, keeping the bearing clean while handling it, and using new or undamaged seals.

Rust damage may also appear after extended storage or non-use periods. This is mainly due to condensation. Prevent this by placing a light coat of petroleum jelly on the bearing when it is placed in storage or by storing bearings in container of oil.

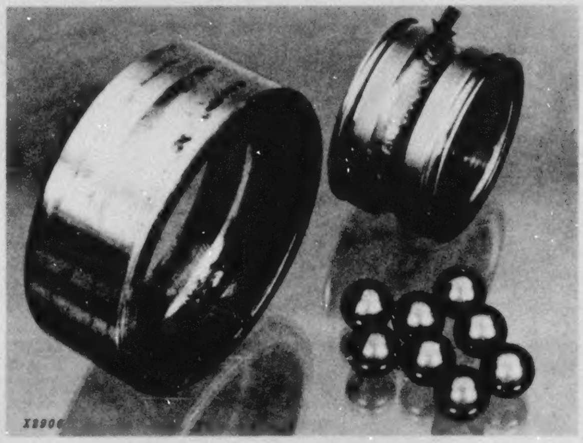


Fig. 57 — Distortion Caused This Premature Failure

Distortion

Distortion of the shaft or housing bore may cause premature fatigue failure (Fig. 57). If the shaft or housing is out-of-round, the rolling elements will be squeezed where there is the least clearance. This increased pressure will cause the race surfaces to flake as happens with normal fatigue. If the housing is out-of-round, regrinding it may solve the problem — the same is true with the shaft. If either cannot be salvaged, then replace the defective parts.

Misalignment

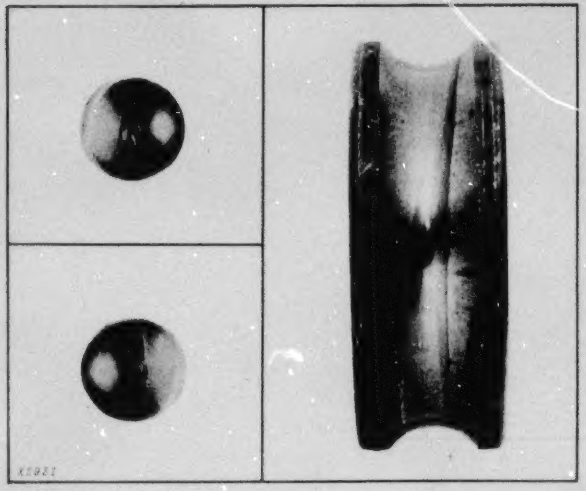

X2921

Fig. 58 — Misalignment Caused This Damage

Misalignment can be caused by a bent shaft, shaft shoulder not square, nonparallel housing bores, out-of-line housing bores, and foreign matter between the bearing and its seat. The typical effects of misalignment is shown in Fig. 58. Notice the paths worn in the races and the worn shape of the balls. Misalignment in roller or needle bearings usually results in extreme pressure on the races and rollers which will result in premature fatigue failure. Determine the cause of failure and correct it or the same damage will result when new bearings are installed.

Improper Fitting

Improper fitting will also cause premature bearing failure. Shown in Fig. 59 are three types of damage resulting from improper fitting.

The first example is a split race caused by forcing the bearing onto a shaft too large for the inside diameter of the bearing race.

The next example is the outer race of a bearing that was damaged by "fit rust" or fretting corrosion which results when the outer race fits too loosely in its housing. Do not sand or remove this rust. This will only increase the loose fit — replace the bearing.

Creep wear, shown in the third example, is caused by too loose of a fit between the shaft and the inside bore of the bearing. As this wear progresses, the inner race will turn faster which will create more friction and heat — leading to eventual bearing failure.

Improper Lubricant

In Fig. 60 you can see why the use of proper lubricant is so important.

The example shows smeared metal. This was caused by the rolling elements sliding across the surface rather than rolling. Too much lubricant that was too solid was used in this bearing. The thick consistency of the lubricant retarded the roll-

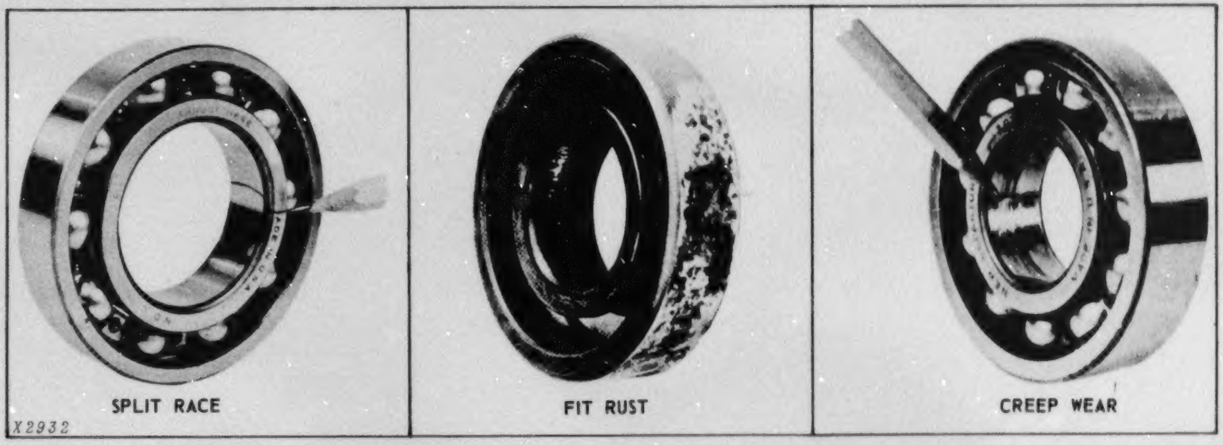
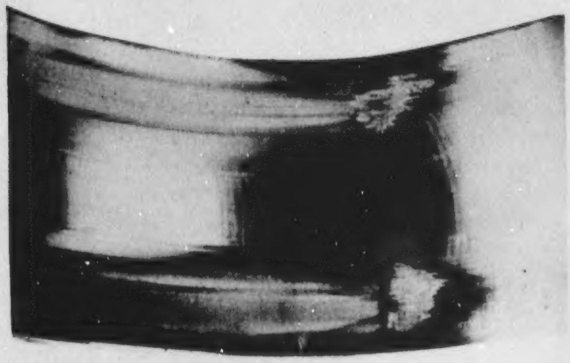


Fig. 59 — Improper Fitting Caused These Failures



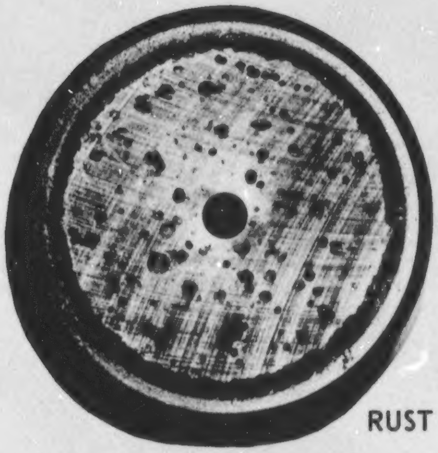


Fig. 60 — Improper Lubricant Caused This Damage

ing elements enough to start the sliding. As the metal surfaces became smeared, the rate of wear increased. This damage can also result from inadequate lubricant.

In the second example (at right) the bearing surface became rusted. Some lubricants have moisture in them, and this will cause rust if there is enough moisture. The same problem will develop if moisture enters the bearing because of a defective seal. Rust will mix with the lubricant and form an abrasive compound which will cause rapid wear.

Always use the lubricant specified by the manufacturer.

Vibration Damage

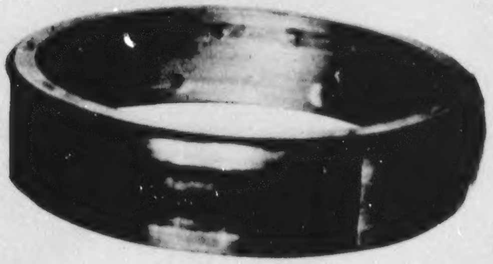


Fig. 61 — Vibration Damage To Bearing

Most anti-friction bearings are rolling while under load. The bearing pictured in Fig. 61, however, was stationary while subjected to *vibration.* The depressions shown are the results of a combination of wear and impacts caused by this vibration.

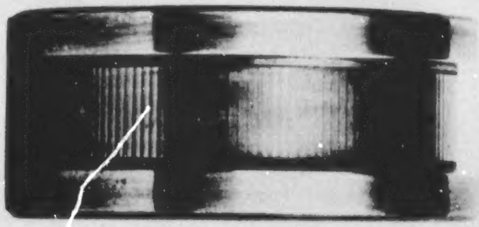


Fig. 62 — Electrical Current Damaged This Bearing

When this bearing is subjected to a rolling load, it will fail very rapidly.

Electrical Current Damage

Where bearings are used in the presence of electricity, potential damage can occur if the *electrical current* passes through the bearing.

Fluting occurs (Fig. 62) as the bearing turns — created by several electrical arcs. These arcs melt the surface metal and lead to bearing failure.

The cause of the electrical leak must be found and corrected or the same thing will occur with a new bearing.

Defects in Bearing Material

Because of excellent quality control, few *defects in material* or manufacturing are found in the bearings made today. However, defects are exceptions that still occur occasionally.

Some of these manufactured "damages" are shown in Fig. 63 on the next page. Often, only a metallurgist can distinguish these types of defects versus the premature failures we just described.

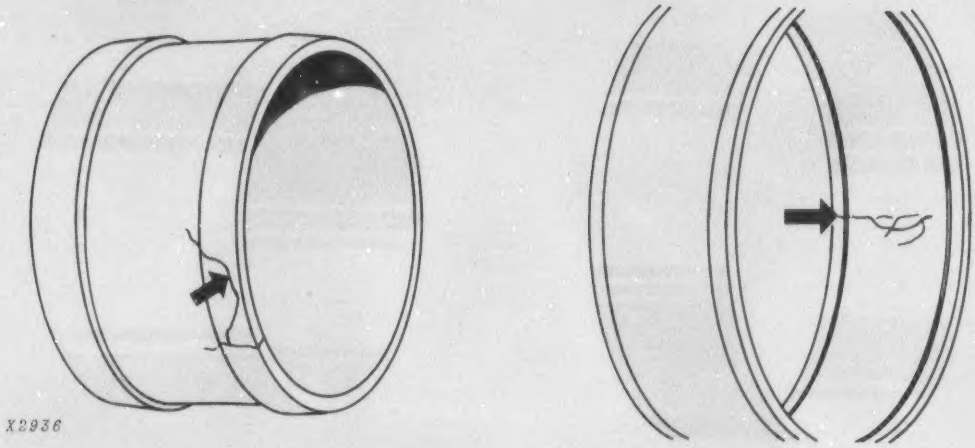
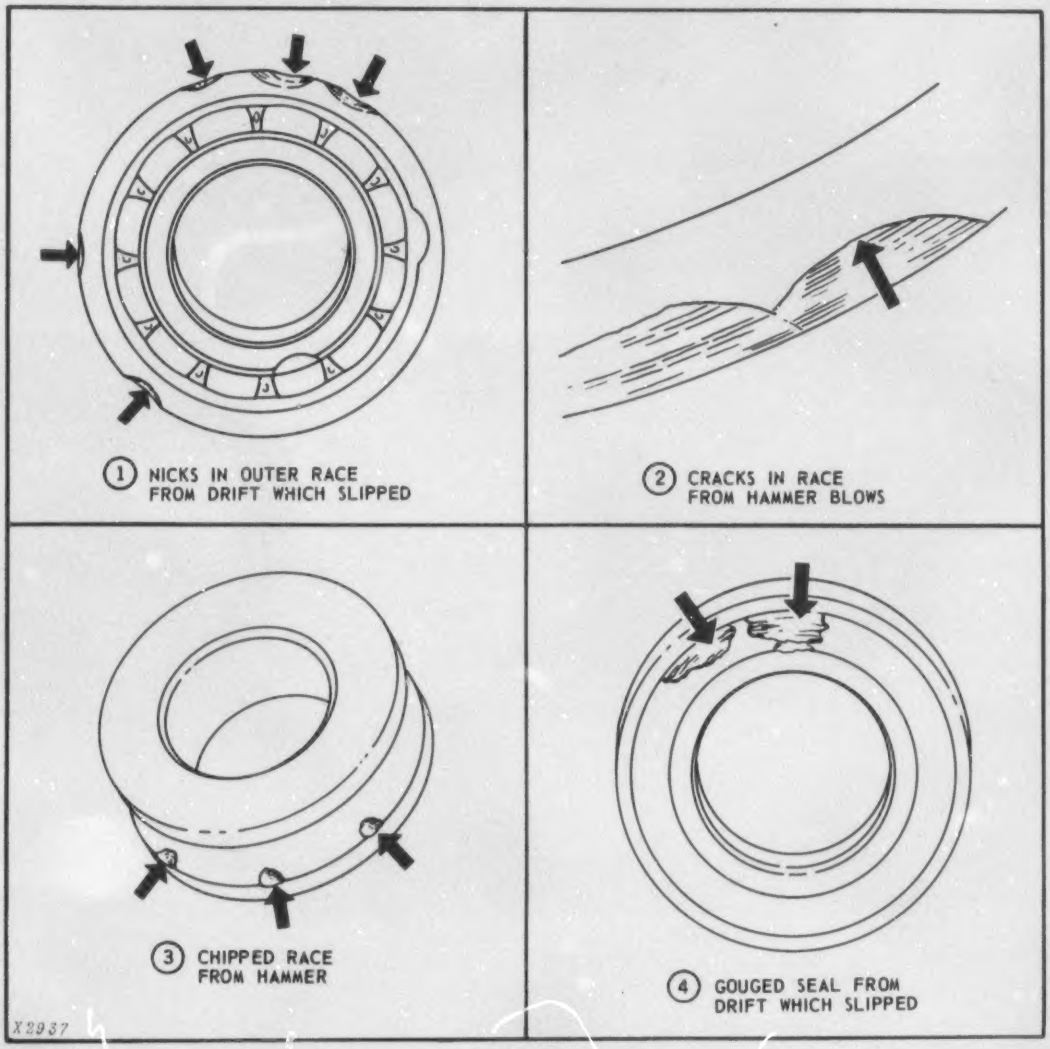


Fig. 63 — Defects In Bearing Material


① NICKS IN OUTER RACE FROM DRIFT WHICH SLIPPED

② CRACKS IN RACE FROM HAMMER BLOWS

③ CHIPPED RACE FROM HAMMER

④ GOUGED SEAL FROM DRIFT WHICH SLIPPED

Fig. 64 — Damage Caused By Improper Service Techniques

Improper Service

If *improper service techniques* are used to remove or install bearings, damage may result which will cause bearing failure.

Fig. 64 on the preceding page illustrates some examples of damaged bearings that were serviced improperly.

Example No. 1 shows nicks in an outer race caused by using a drift to drive the bearing. Example No. 2 is of cracks caused by striking the race with hammer.

The results of this hammering also damages the inner race as shown in Example No. 3. When the race is struck a severe blow, this force is transmitted through the rolling elements to the other race and causes the chipping shown.

Another serious result of using improper tools is the damaged seal shown on the sealed bearing in No. 4. A drift slipped and gouged this seal. The seal's effectiveness is reduced and the separator is probably put in a bind — both problems may lead to premature failure of the bearing.

See the "Removal" and "Installation" techniques described elsewhere in this chapter for proper servicing techniques.

LUBRICATION OF ANTI-FRICTION BEARINGS

Anti-friction bearings do not normally wear out — they fail because of fatigue. The flexing, loads, and heat eventually cause the metal to lose its strength. Of course, anti-friction bearings will wear out if they are not lubricated properly.

A lubricant must do three jobs to perform well:

1. Maintain a film of lubricant between all elements of the bearing to prevent rubbing.

2. Reduce friction between balls or rollers and the separators.

3. Prevent rust by coating all parts with a protective coating.

Methods of Lubrication

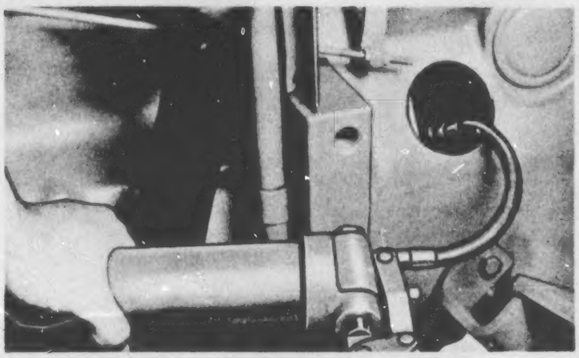


Fig. 65 — Applying Grease To Pressure Fitting Using Hand Gun

In addition to applying lubricant to bearings with a grease gun as shown in Fig. 65, packing and splash methods are also used. Keep in mind that the design and application of the bearing determines the type of lubricant required and the frequency of lubrication. Always follow the manufacturer's recommendations. He knows what the requirements are to insure long bearing life.

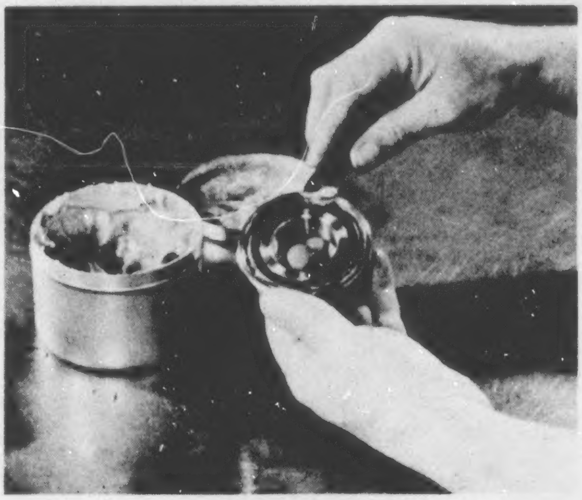


Fig. 66 — Packing A Bearing By Hand

Some bearings, such as wheel bearings, require infrequent lubrication. These bearings are usually packed with grease by either using a grease packer or by hand packing as shown in Fig. 66.

40

Remember that too much lubrication can be as harmful as too little. If too much grease is applied to a bearing, churning will cause friction and heat, leading to premature bearing failure. Again, follow the manufacturer's instructions.

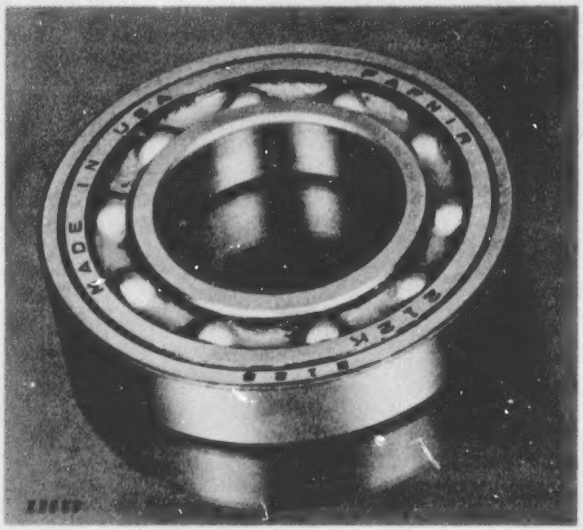


Fig. 67 — Properly Packed Ball Bearing

As a general rule, *pack anti-friction bearings half full.* Remove any excess lubricant. In Fig. 67 you can see a properly packed ball bearing. With both ball and roller bearings, pack both sides even with the cages. Then rotate the races a few times to remove excess grease.

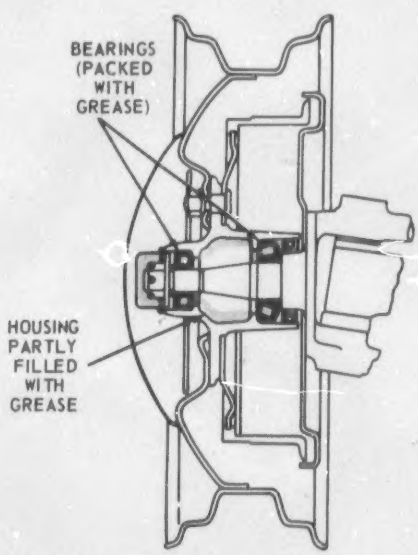

BEARINGS (PACKED WITH GREASE)
HOUSING PARTLY FILLED WITH GREASE
XE946

Fig. 68 — Partially Fill Housing With Grease

Before installing the bearings into the housing, partially fill the housing with grease (Fig. 68). Do not completely fill the housing — this will cause churning of the grease and will result in heat and eventual bearing failure. Add only enough grease to prevent thinned grease from running out of the bearings.

In splash systems of lubrication, such as in transmissions, the most important concerns are:

1. *Keep sufficient lubricant in the housing.*
2. *Use the correct lubricant.*
3. *Change lubricant at recommended intervals.*
4. *Use lubricant rated for proper temperature. Higher temperatures than recommended for a given lubricant will break down extreme-pressure additives.*

Usually, filler plugs or caps provide a means of filling the housing.

NOTE: For more on lubricants, see the FOS manual on "Fuels, Lubricants, and Coolants."

INSTALLATION OF BEARINGS

Proper installation is important if bearing damage is to be prevented. Fig. 69 on the next page shows several *acceptable* methods that can be used to install bearings without damaging them. (Fig. 70 shows the *wrong* methods.)

The first examples (1) show two proper methods of pressing an inner race on a shaft. Notice that no pressure is exerted on the outer race.
When pressing the outer race into a housing (2), apply pressure to the outer race only as shown in the next example.

A push-puller (3) may be used in certain situations to install a bearing. When care is taken, a race may be driven onto a shaft with a hammer and tube as shown in (4).

Needle bearings (5) require a special driver which is undercut as shown by the inset drawing. This undercut is shaped to transmit the driving force to the *outer* shell — preventing the bearing shell from buckling.

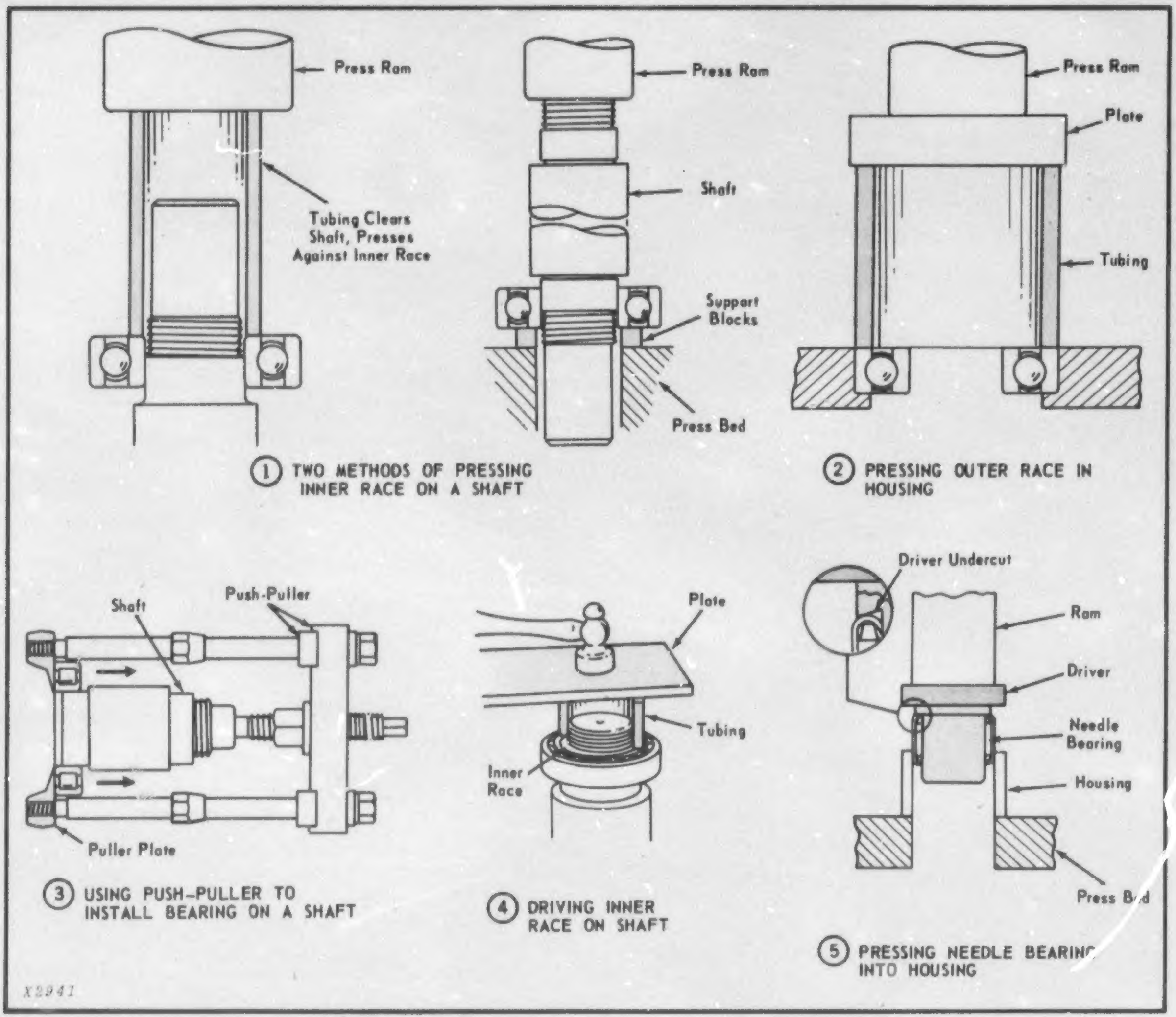
CAUTION: Oil vapor may catch fire when heated or near a flame; be careful.

Some bearings have a very tight fit on the shaft and must be heated for ease in assembly. If the bearing is small, it can be heated in a container of oil to no more than 300°F (149°C). The bearing must not contact the bottom of the container because it will absorb the heat directly and may be damaged. Remember that bearings are heat treated to harden them. If the bearing gets too hot, it will lose some of its hardness.

A better method of heating bearings for installation is by inserting a light bulb into the bearing bore (if the bore is large enough). Use a cover over the bearing and bulb to retain the heat until the bearing is ready for installation. This method is less hazardous to both the bearing and you. The fire danger is eliminated. The bearing damage due to high temperatures is eliminated also.

Bearings may be installed haphazardly and result in bearing damage. Many of these *wrong* methods are shown in Fig. 70.

Always press on the bearing race that is the press fit — never on the slide-fit race as shown in (A) and (D), Fig. 70.


Press Ram
Tubing Clears Shaft, Presses Against Inner Race
Press Ram
Shaft
Support Blocks
Press Bed
Press Ram
Plate
Tubing
Shaft
Push-Puller
Puller Plate
Plate
Tubing
Inner Race
Driver Undercut
Ram
Driver
Needle Bearing
Housing
Press Bed
X2941

① TWO METHODS OF PRESSING INNER RACE ON A SHAFT

② PRESSING OUTER RACE IN HOUSING

③ USING PUSH-PULLER TO INSTALL BEARING ON A SHAFT

④ DRIVING INNER RACE ON SHAFT

⑤ PRESSING NEEDLE BEARING INTO HOUSING

Fig. 69 — Proper Installation Techniques For Anti-Friction Bearings

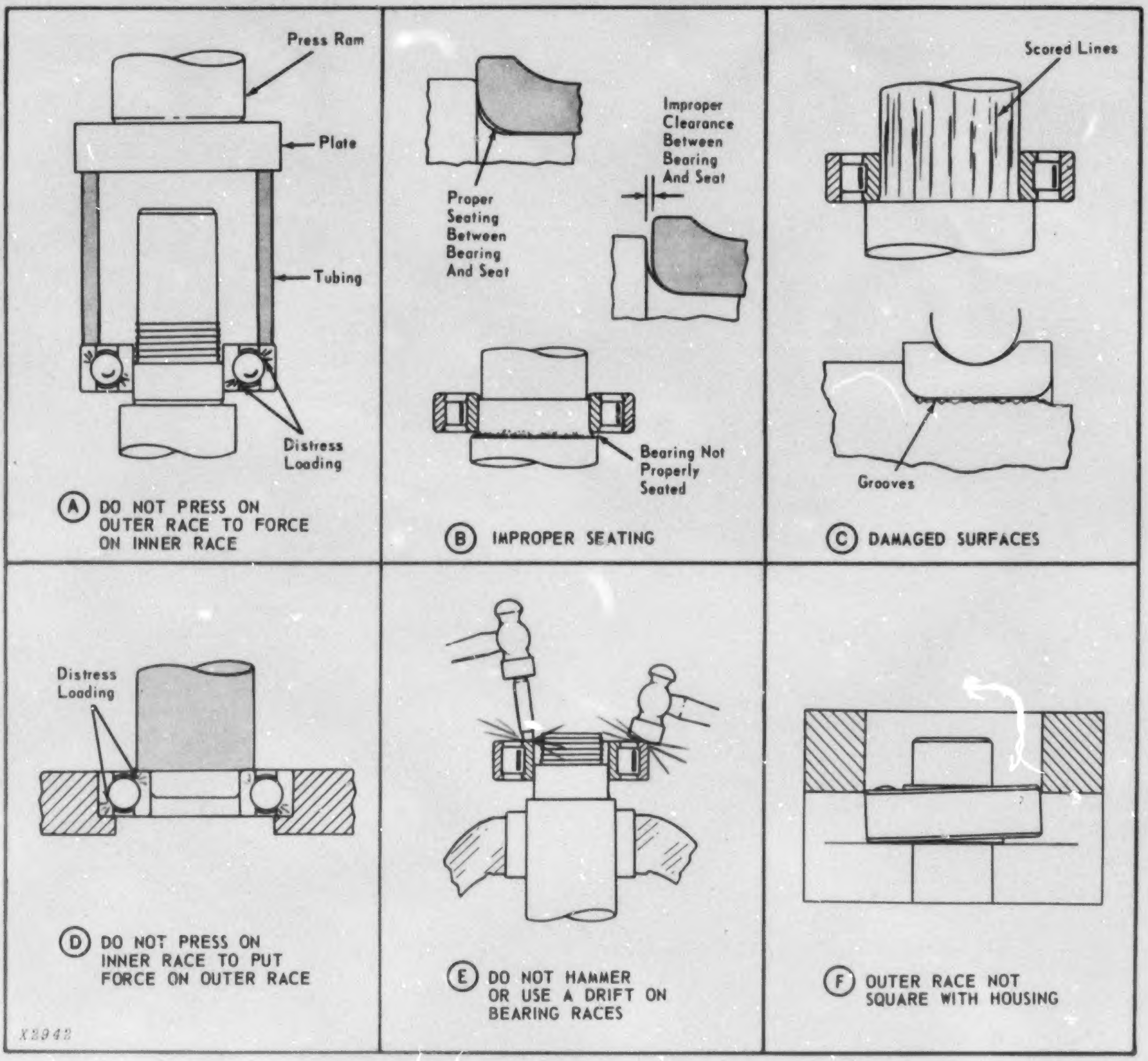

Press Ram
Plate
Tubing
Distress Loading
A DO NOT PRESS ON OUTER RACE TO FORCE ON INNER RACE
Proper Seating Between Bearing And Seat
Improper Clearance Between Bearing And Seat
Bearing Not Properly Seated
B IMPROPER SEATING
Scored Lines
Grooves
C DAMAGED SURFACES
Distress Loading
D DO NOT PRESS ON INNER RACE TO PUT FORCE ON OUTER RACE
X3942
E DO NOT HAMMER OR USE A DRIFT ON BEARING RACES
F OUTER RACE NOT SQUARE WITH HOUSING

Fig. 70 — Improper Installation Techniques For Anti-Friction Bearings

Be sure that the bearing is properly seated on the shaft or in the housing (B). Some bearings have sharp edges and will not seat where a fillet is present.

Also be certain that the shaft or housing is clean — free of dirt or metal particles (C).

This foreign matter can prevent the bearing from seating completely. A bearing that is not seated properly may be subjected to high preload which will cause premature failure.

A damaged shaft or housing surface may also lead to short bearing life. Score or grooved surfaces (C) will peen down under load and the bearing race will turn because clearance is increased. As described earlier, when bearing creep occurs at a rapid rate, friction and heat increase, causing bearing failure. Do not hammer or use a drift on bearing races (E). This will damage the races and the rolling surfaces; see "Diagnosis of Failures."

Be certain that the outer race is square with the housing when installing bearings (F). A bearing can be severly damaged if it is "cocked" while being pressed into a housing.

Now that we have looked at installation techniques, let's talk about adjustments.

ADJUSTMENT OF BEARINGS

Many anti-friction bearings are mounted so that no adjustment is required. Usually bearings that do not require adjustment are mounted with one bearing "floated" and the other secured by one of several means.

Those bearings that do require adjustment are usually fixed in place by securing them with one of the devices described in "Mountings." This adjustment is called *preloading*.

Preloading is used to reduce deflection and provide proper running conditions where dynamic loads are present.

In instances where preloading is specified, care must be taken not to set the preload too tight. This will cause heat to build up and the bearing will fail. If too little preload is used, the supported parts will deflect excessively and rapid wear will result.

Consult Technical Manual or Service Manual specifications for the proper preload for each bearing you install.

To prevent serious damage to components using anti-friction bearings, it is important to know what symptoms indicate trouble. This brings us to trouble shooting.

TROUBLE SHOOTING OF ANTI-FRICTION BEARINGS

Properly maintained anti-friction bearings should be relatively trouble-free. Use the following chart to determine cause and remedy of any bearing failure symptoms.

If the suggested remedy does not correct the problem, then disassemble the bearing and determine the cause.

Refer to "Diagnosis of Failures" to help identify failures.

Possible Causes	Symptoms				Remedy
	Excessive Noise and Vibration	Excessive Heat	Lubricant Loss	Shaft Resistant To Turning	
Insufficient lubrication.	X	X			Fill with correct amount of proper lubricant.
Incorrect lubricant.	X	X		X	Use recommended lubricant.
Defective bearing.	X				Replace bearing.
Dirt.	X			X	Clean bearing. Replace seals and bearing if damaged.
Corrosion.	X			X	Use lubricant that resists corrosion. Replace bearing.
Improper load.	X	X		X	Adjust to specification.
Misalignment.	X	X			Determine what is misaligned: housing, shaft, or bores. Shaft may be bent or housing bores not aligned. Replace shaft or housing.
Bearings fit too loose.	X				Chrome plate or metalize shaft or bore and regrind to specification or replace bearing if seating surfaces are worn.
Improper mounting.	X				Bearing mounted crooked or put in a bind causing excessive preload.
Improper lubricant.			X		Use high-temperature grease.
Lubricant churning.		X			Use less lubricant or use a lower-viscosity lubricant. Be sure to use recommended lubricant.
Excessive creep.		X			Either inner or outer race is sliding around its seated surface. Build up shaft or housing or replace bearing, whichever is applicable.
Leakage through seal.			X		Replace seal. Check shaft for scratches or burrs that may have damaged seal
Lack of lubrication.				X	Add proper lubricant. Check for damage.
Seal tight.				X	Use proper size and type of seal.
Bearing cocked.				X	Remove bearing and clean all mating surfaces. Reinstall bearing if not damaged.
Leakage between bearing caps and housing.			X		Replace gasket.

TEST YOURSELF

QUESTIONS

1. Name three of the four main jobs of bearings?

2. What are the two load forces concerning bearings?

3. Regarding plain bearings, what state of lubrication is the most desirable?

4. Why is bearing crush important?

5. What determines the load carrying capacity of anti-friction bearings?

6. A full-type ball bearing was used as a replacement for a Conrad bearing; the full-type bearing soon failed. Why did it fail?

7. You are installing anti-friction bearings in a bearing housing and on a shaft that turns. What race of the bearing is going to be the press fit?

8. You are going to press a ball bearing onto a shaft — what must you be careful *not* to do?

9. If an anti-friction bearing fails due to normal use, what is the failure called?

10. If an anti-friction bearing suffers fatigue failure prematurely, what is the most likely cause?

(Answers in back of text.)

SEALS / PART 2

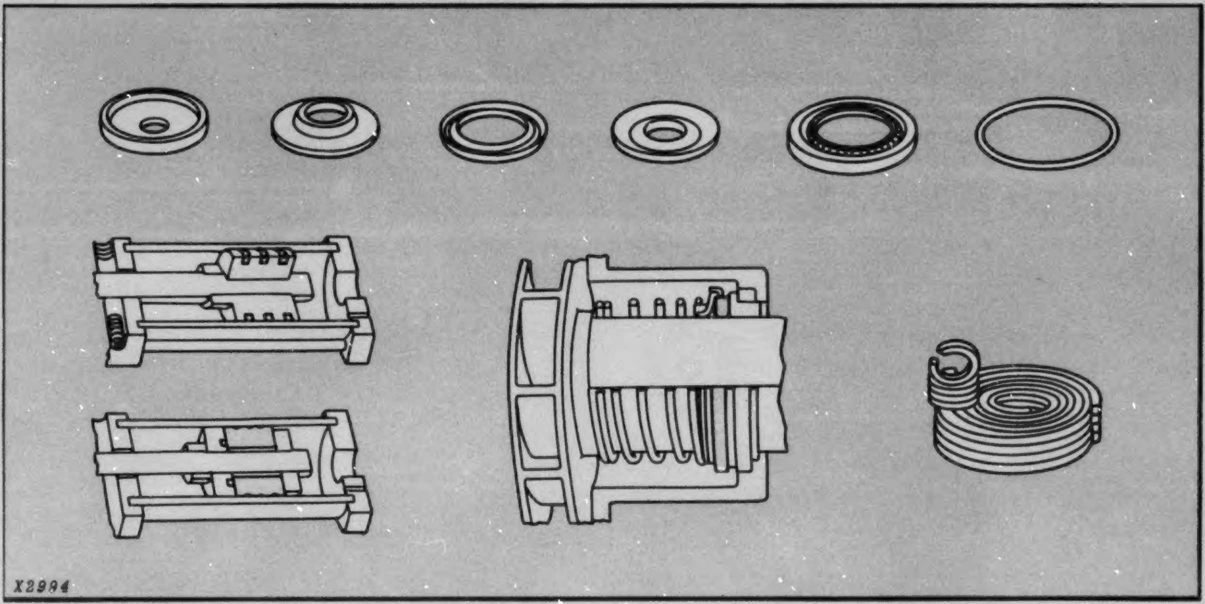


Fig. 1 — Various Types Of Seals

TYPES OF SEALS

All modern equipment uses **seals** to keep in fluids, keep out dirt, and sometimes to hold pressures or vacuums.

There are two basic types of seals:

- **Dynamic — to seal moving parts**
- **Static — to seal fixed parts**

DYNAMIC SEALS (Fig. 2) include shaft and rod seals, compression packings, and piston rings.

STATIC SEALS are usually gaskets, but may also be O-rings or packings.

Another category of static seals are **sealants,** which are similar to gaskets except that they are *applied* as a liquid or paste.

Listed in the box on the next page are all the seals we will cover in this chapter.

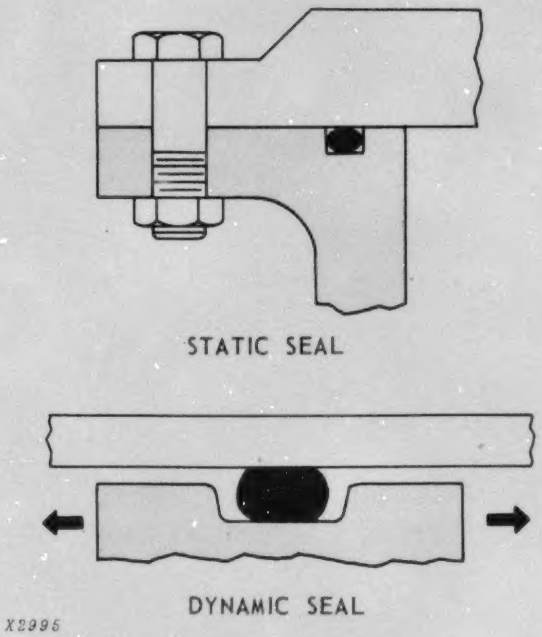


Fig. 2 — Static And Dynamic Seals

DYNAMIC SEALS

Radial Lip Seals

Exclusion Seals

Clearance Seals

Ring Seals

Face Seals

Compression Packings

Molded Packings

Diaphragm Seals

STATIC SEALS

Nonmetallic Gaskets

Metallic Gaskets

Static O-Rings

SEALANTS

Hardening Types

Nonhardening Types

Tapes

The perfect seal should prevent all leakage. However, this is not always practical or even desirable. In dynamic uses, for example, slight leakage as a fluid *film* aids in lubrication and cooling of moving parts. The point to keep in mind is that each type of seal has a different function.

Seals appear to be simple objects when held in the hand. But in use they are complex, precision parts and must be treated carefully if they are to do their jobs properly. Remember — seals are a vital defense against leaks at the critical openings or joints in all modern machines.

HOW SEALS ARE SELECTED

The designer of a system has many factors to consider when choosing a seal. Some of these are:

1. *Will the seal resist all pressures expected?*
2. *Can the seal withstand the heat of operation?*
3. *Will the seal wear out too rapidly?*
4. *Will the seal be harmed by the fluid or gas?*
5. *Does the seal fit without dragging on the moving parts?*
6. *Will the seal score or scratch polished metal parts?*

Each application for a seal presents a different set of problems. This is why so many seals are on the market today. And why the right choice of a seal for replacement is so important. Always follow the manufacturer's recommendation.

Remember that all seals are identified either by a part number on the case or by other markings (as paint slashes on O-rings). These identifications tell you if the seal is meant for your application, if it can resist the temperatures, the chemicals in the system fluid, etc.

DYNAMIC SEALS

In this section we will cover all the **dynamic** seals listed in the box at left.

RADIAL LIP SEALS

Radial lip seals are used primarily for keeping lubricants in systems which have moving shafts.

These seals are also called *oil seals* or *shaft seals.*

A typical lip seal is shown in Fig. 3. All major elements are named (SAE nomenclature). The basic parts are the outer metal case and the inner flexible sealing element.

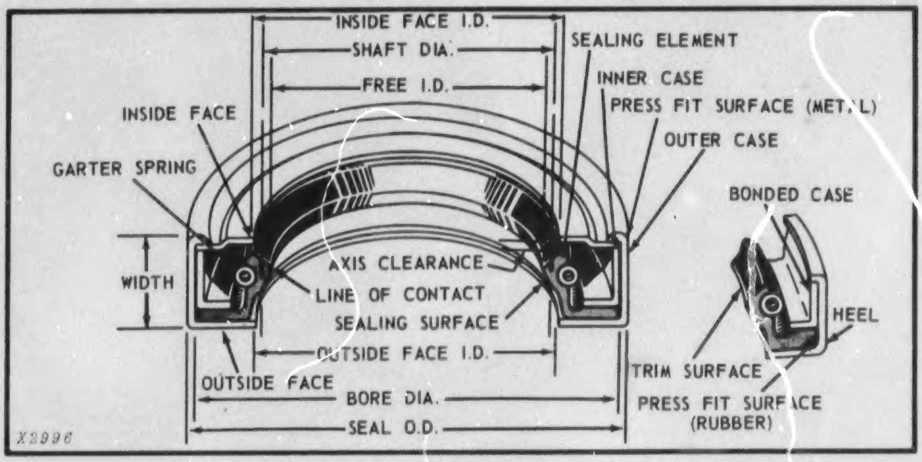

INSIDE FACE I.D.
SHAFT DIA.
FREE I.D.
SEALING ELEMENT
INNER CASE
PRESS FIT SURFACE (METAL)
INSIDE FACE
OUTER CASE
GARTER SPRING
BONDED CASE
WIDTH
AXIS CLEARANCE
LINE OF CONTACT
SEALING SURFACE
HEEL
OUTSIDE FACE I.D.
OUTSIDE FACE
TRIM SURFACE
BORE DIA.
PRESS FIT SURFACE (RUBBER)
SEAL O.D.
X2996

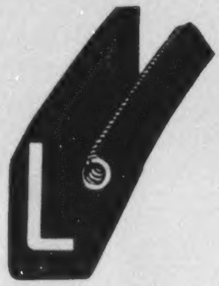
Fig. 3 — Radial Lip Seal

ADVANTAGES

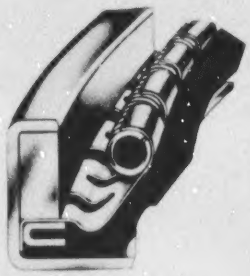
Basic advantages of lip seals are:

1. *Fit into small space.*
2. *Fairly low cost.*
3. *Easy to install.*
4. *Handle many variables while sealing.*

Variables include most oils and hydraulic fluids over wide temperature ranges, moderate fluid pressures, average misalignment, dynamic shaft runout, and variations in shaft speed.



BONDED SEAL



ASSEMBLED SEAL

Fig. 4 — Basic Types Of Radial Lip Seals

TYPES

Two basic types of radial lip seals are:

- **Bonded seals**
- **Assembled seals**

In the BONDED seal (Fig. 4), the flexible sealing element is formed and bonded to the metal case in one operation.

In the ASSEMBLED seal (Fig. 4), the parts are made separately and assembled into the outer case, which is then crimped or rolled.

OPERATION

Sealing of a lip-type seal is normally the result of an interference fit between the flexible sealing element and the shaft. Usually spring pressure behind the lip is also added. Keeping the fluid in depends upon a precise amount of lip contact pressure.

The seal lip should ride on a thin film of lubricant.

The film does the sealing so it must be controlled precisely by the mechanical pressure of the sealing element and the shaft finish.

If the fluid film gets too thick, fluid leaks; if too thin, the lip wears and friction, heat, and lip oscillations can result.

Normally, if contact pressure increases, the film gets thinner. Heat build-up can also reduce the fluid film.

Never run lip seals without lubrication unless necessary — and then only for short periods.

Unless defective or installed wrong, lip seals should leak only the thin fluid film we discussed above.

SELECTION OF LIP SEALS

Radial lip seals are classified by lip types as follows:

- **Single Lip** (Fig. 5, A). Lip not spring-loaded. For containing viscous fluids like grease, at slow shaft speeds.

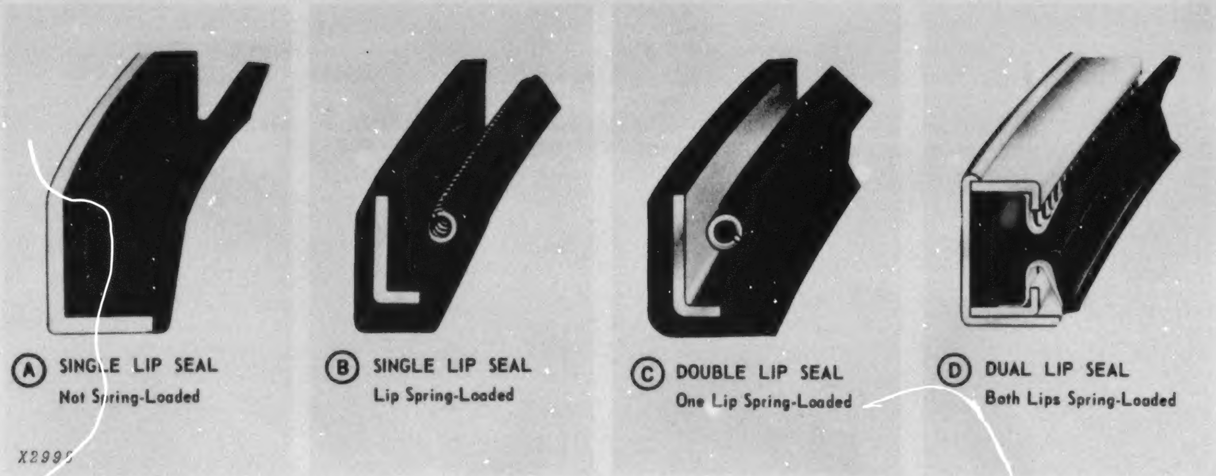

Ⓐ SINGLE LIP SEAL
Not Spring-Loaded
Ⓑ SINGLE LIP SEAL
Lip Spring-Loaded
Ⓒ DOUBLE LIP SEAL
One Lip Spring-Loaded
Ⓓ DUAL LIP SEAL
Both Lips Spring-Loaded
X2998

Fig. 5 — Basic Lip Types Of Radial Lip Seals

- **Single Lip Spring-Loaded** (Fig. 5, B). For retaining lower-viscosity lubricants at higher shaft speeds in clean atmospheres.

- **Double Lip** (Fig. 5, C). Lips face opposite, one spring-loaded, one not. For retaining lubricant on spring-loaded side, while keeping out dirt on the other side.

- **Dual Lip** (Fig. 5, D). Lips face opposite, both are spring-loaded. For containing lubricant on one side and excluding fluid on the other.

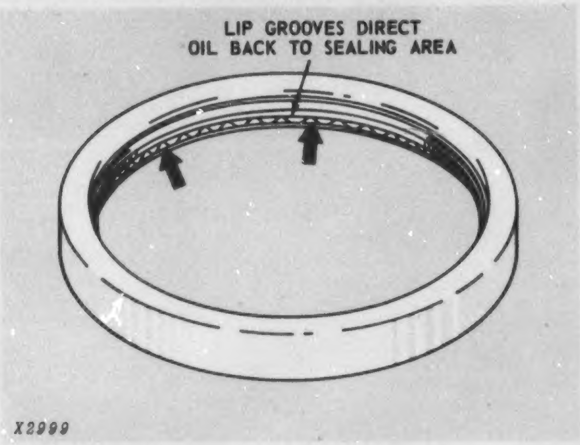

LIP GROOVES DIRECT
OIL BACK TO SEALING AREA
X2999

Fig. 6 — Hydrodynamic Seal

Other special lip seals include:

1. **Split seals** for difficult installations.

2. **External seals** for a fixed shaft and rotating bore (outer part of seal is the sealing surface).

3. **Hydrodynamic seals** (Fig. 6) which have grooves or ribs molded into the seal lip to direct oil flow back into the sealing area, reducing heat and wear. This seal can operate at less lip pressure than standard lip seals. It works best for one-direction rotation at fairly high surface speeds.

LIP SEAL FAILURES

Lip seals have sealing elements of rubber or synthetics which require special care. Metal cases can also be bent or "cocked." Some of the major service problems and procedures are given below.

Checking Seals For Leakage

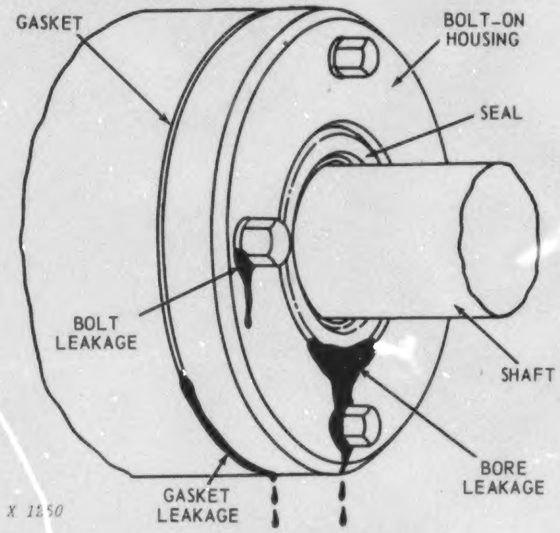

GASKET
BOLT-ON
HOUSING
SEAL
SHAFT
BOLT
LEAKAGE
GASKET
LEAKAGE
BORE
LEAKAGE
X 1250

Fig. 7 — Common Types Of Oil Leaks

Before disassembly, check out the causes of leakage. This may prevent a repeat seal failure, caused by problems other than the oil seal.

Before cleaning the area around the seal, find any paths of leakage (Fig. 7). Sometimes leakage may be from sources other than the seal — worn gaskets, loose bolts, cracked housings, or loose line connections.

Inspect the sealing area of the seal to see if it is wet or dry. If wet, see whether the oil is running out or is merely a lubricating film.

Removing Seals

During removal, continue to check for causes of leakage.

Check both the inner and outer parts of the seal for wet oil which means leakage.

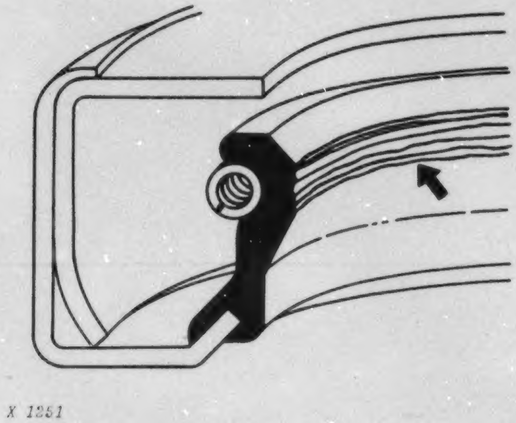


Fig. 8 — Seal Worn By Rough Shaft

When removing the seal, inspect the sealing lips (Fig. 8) before washing them. Look for unusual wear, warping, cuts and gouges, or particles embedded in the seal.

On spring-loaded lip seals, be sure the spring is seated around the lip, and that the lip was not damaged when first installed.

Normally, do not disassemble the unit any more than necessary to replace the faulty seals.

Checking Shafts And Bores

Check shafts for roughness at seal contact areas (Fig. 9). Look for deep scratches or nicks that could have damaged the seal.

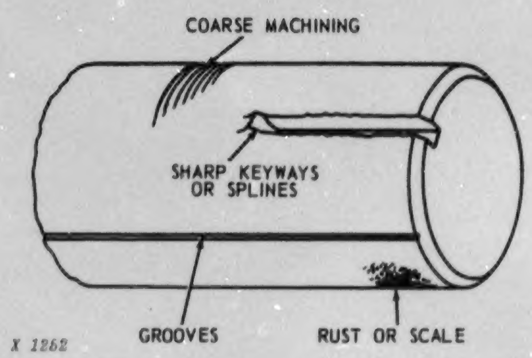


Fig. 9 — Shaft Conditions Which Can Damage Seals And Cause Leakage

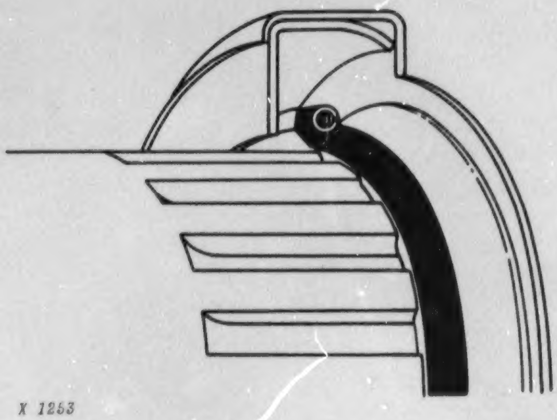


Fig. 10 — Shaft Splines Or Keyways Can Damage Seals During Installation

Find out if a shaft spline, keyway, or burred end could have caused a nick or cut in the seal lip during installation (Fig. 10).

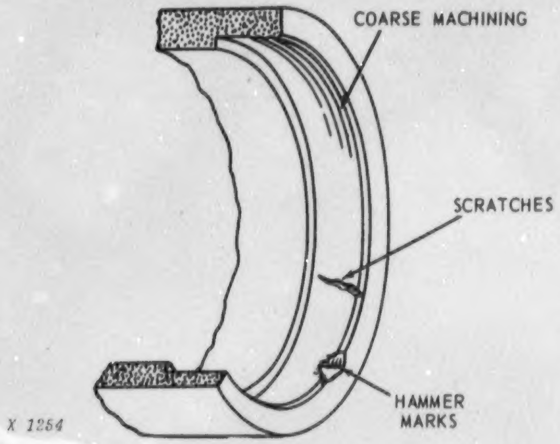


Fig. 11 — Bore Conditions Which Can Damage Seals And Cause Leakage

Inspect the bore into which the seal is pressed (Fig. 11). Look for nicks and gouges that could create a path of oil leakage. A coarsely machined bore can allow oil to seep out by a spiral path. Sharp corners at the bore edges can score the metal case of the seal when it is pressed in. These scores can make a path for oil leakage.

Some engines contain replaceable wear sleeves on the crankshaft (Fig. 12). When the sleeve is removed, clean the surface onto which the sleeve is mounted.

Before installing new wear sleeve check for nicks or scratches due to improper handling.

Apply a sealing compound on the inside of a new sleeve. Then install with the proper tools to avoid damage to the sleeve.

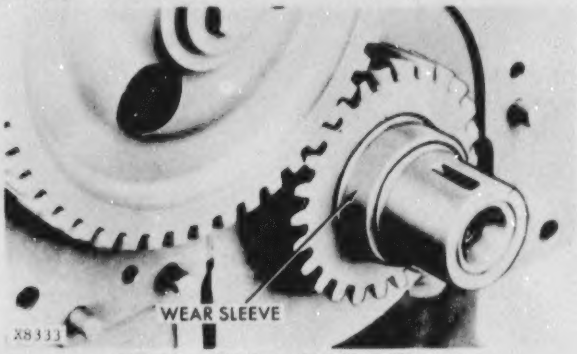


Fig. 12 — Replaceable Wear Sleeve

Checking Seals For Compatibility With Fluids Or Operating Temperatures

Some lubricants are harmful to certain seals, especially rubber lips. An incorrect oil can either harden or soften the synthetic rubber in seals and so damage them.

If the seal lip is "spongy," this probably means that the seal and the fluid are not compatible. If the seal is factory-approved, then an improper fluid may have been used in the system.

Hardening of the seal lip can be caused by either heat or chemcial reaction with an improper fluid.

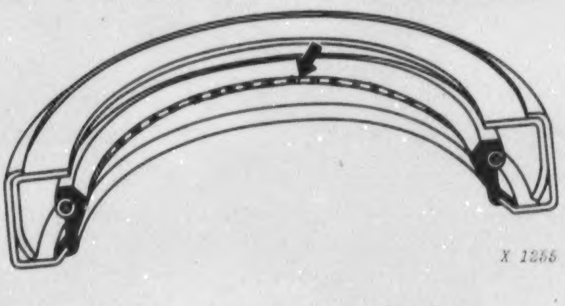


Fig. 13 — Seal Lips Damaged By Heat

Hardening of the seal lip on the area of shaft contact (Fig. 13) is generally the result of *heat* from either the shaft or the fluid.

INSTALLING LIP SEALS

To get the best use of seals, proper handling and installation are vital. Lip seals are fragile and can be easily damaged.

To prevent this, keep seals protected in their containers until ready for use. Store them in a cool, dry place free of dirt. Seals should be given the same care as precision bearings.

As a general rule, **replace all seals that are disturbed during repair of the system.** The price of a few seals is economical compared to a return repair job to correct leaks.

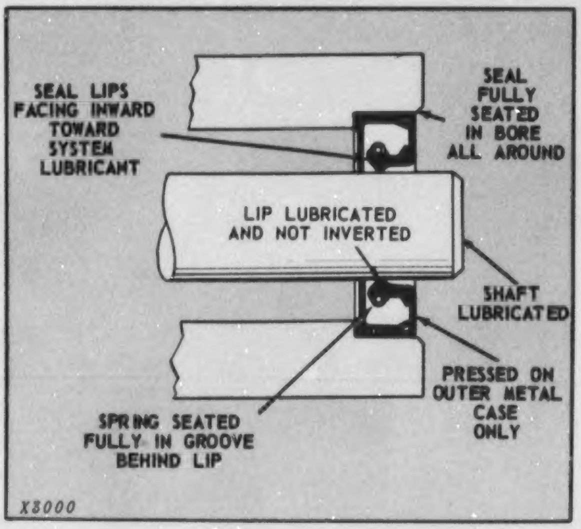

SEAL LIPS FACING INWARD TOWARD SYSTEM LUBRICANT
SEAL FULLY SEATED IN BORE ALL AROUND
LIP LUBRICATED AND NOT INVERTED
SHAFT LUBRICATED
PRESSED ON OUTER METAL CASE ONLY
SPRING SEATED FULLY IN GROOVE BEHIND LIP
X8000

Fig. 14 — Radial Lip Seal Which Has Been Properly Installed

Here are some rules for seal installation:

1. Install seals recommended by the manufacturer of the machine.
2. Use the fluids recommended in the machine operator's manual.
3. Keep the seals and fluids clean and free of dirt.
4. Before installing seals, clean the shaft or bore area. Inspect these areas for damage. File or stone away any burrs or bad nicks and polish with a fine emery cloth for a ground finish, then clean the area to remove metal particles. In dynamic applications, the sliding surface for the seal should usually have a mirror finish for best operation.

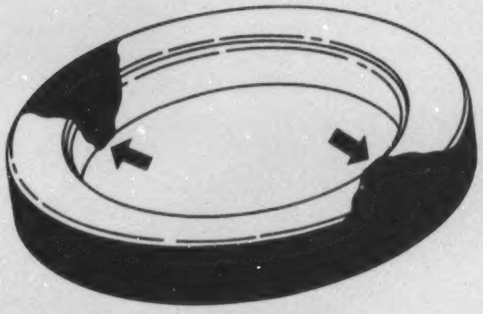


Fig. 15 — Too Much Sealant On Case Runs Onto Sealing Lips.

5. On seals with single lips, the lip should normally face in **toward** the system lubricant. (This is usually the garter spring side).

6. Lubricate the seal, especially any lips, and the shaft to ease installation. Use the system fluid to lubricate the seal and shaft.

7. With metal-cased seals, coat the seal's outside diameter with a **thin** film of gasket cement to prevent bore leakage. Do not allow excess cement to run onto sealing lips (Fig. 15).

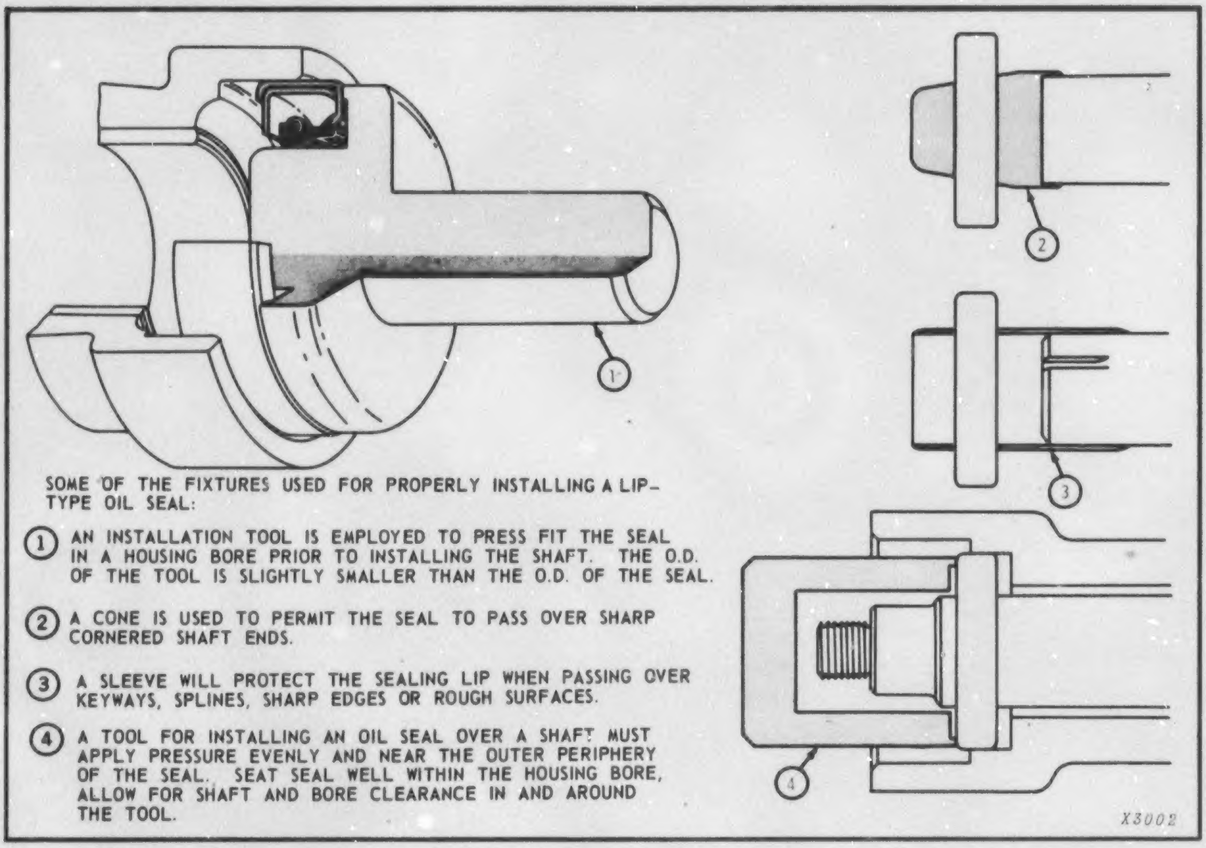
NOTE: Pre-coated seals do not require cement on the bore fit.

8. Use a factory-recommended tool to install the seal properly (Fig. 16, No. 1 and 4). This is very important with pressed-in seals. If a seal driving tool is not available, 1) use a circular ring such as an old bearing race that contacts the seal case near the outer diameter, or 2) use a square wooden block. **Do not use sharp tools, and never press on the sealing lip — only the outer metal case.**

9. Use a cone or sleeve to protect the sealing lip when installing the seal over sharp corners of shafts, keyways, or splines (Fig. 16, No. 2, 3).

10. Shim stock can also be used to protect seals when installing them over sharp edges such as shaft splines. Place *rolled* plastic shim stock (0.003-0.010 inch [0.076-0.25 mm]) over the sharp edge, then pull it out after the seal is in place.

11. Be sure the seal is driven in evenly to prevent "cocking" of the seal (Fig. 17 on next page). A cocked seal allows oil to leak out and dirt to enter as shown. **Be careful not to bend or "dish" the flat metal area of metal-cased seals. This causes the lips to be distorted.**



SOME OF THE FIXTURES USED FOR PROPERLY INSTALLING A LIP-TYPE OIL SEAL:

① AN INSTALLATION TOOL IS EMPLOYED TO PRESS FIT THE SEAL IN A HOUSING BORE PRIOR TO INSTALLING THE SHAFT. THE O.D. OF THE TOOL IS SLIGHTLY SMALLER THAN THE O.D. OF THE SEAL.

② A CONE IS USED TO PERMIT THE SEAL TO PASS OVER SHARP CORNERED SHAFT ENDS.

③ A SLEEVE WILL PROTECT THE SEALING LIP WHEN PASSING OVER KEYWAYS, SPLINES, SHARP EDGES OR ROUGH SURFACES.

④ A TOOL FOR INSTALLING AN OIL SEAL OVER A SHAFT MUST APPLY PRESSURE EVENLY AND NEAR THE OUTER PERIPHERY OF THE SEAL. SEAT SEAL WELL WITHIN THE HOUSING BORE, ALLOW FOR SHAFT AND BORE CLEARANCE IN AND AROUND THE TOOL.

Fig. 16 — Tools For Properly Installing Lip-Type Oil Seals

12. After assembly, always check the unit by hand for free operation if possible before starting up the system.

13. Try to prevent dirt and grit from falling on shafts and being carried into the seal. This material can quickly damage the seal or score the metal surfaces.

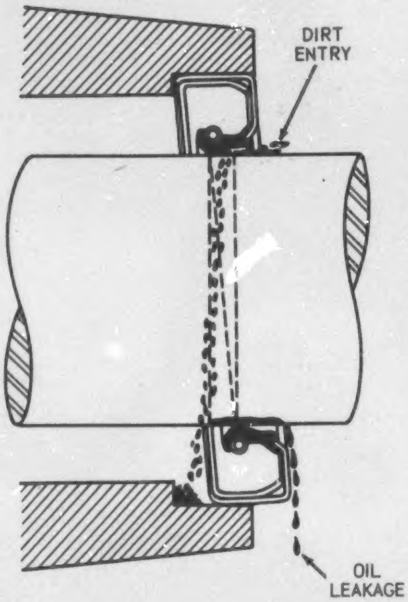


Fig. 17 — Cocked Seals Allow Dirt To Enter And Oil To Leak Out

Run-In Checking Of New Lip-Type Seals

When a new lip-type seal is installed on a clean shaft, a break-in period of a few hours is required to seat the seal lip with the shaft surface. During this period, the seal polishes a pattern on the shaft and the shaft in turn seats the lip contact, wearing away the knife-sharp lip contact to a narrow band.

During this period, slight seepage may occur. After seating, the seal should perform without any measurable leakage.

EXCLUSION SEALS

Exclusion seals are used to prevent entry of foreign material into the moving parts of machinery. This protection is necessary because dirt can contaminate the lubricant and accelerate wear and corrosion.

Static joints are easily sealed by tight fits and gaskets. Sealing between parts having relative motion, such as between a housing and a moving shaft, is more difficult.

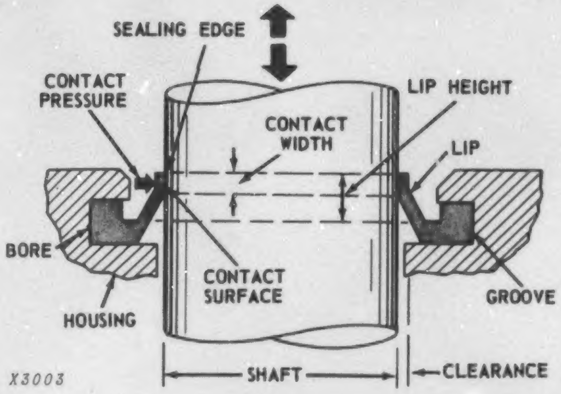


Fig. 18 — Radial Exclusion Seal

Never use seals designed only for inclusion for excluding jobs, except for very light service. They usually cannot do the job properly and also are damaged by even small amounts of abrasive material.

Exclusion seals can be classified into four general groups:

- **Wipers**
- **Scrapers**
- **Axial Seals**
- **Boots**

Fig. 18 is a diagram of a typical radial exclusion seal.

WIPERS

Exclusion seals with lips of leather, elastic, or similar material are commonly called wipers when they are used on reciprocating shafts (see Fig. 18). Many of these can also be used on rotating shafts. These seals resemble radial lip seals.

The active sealing element or lip is usually a part extending outward and contacting the shaft. Sufficient radial or contact pressure must be provided to keep the contact surface against the shaft. Pressure is supplied by the band or cantilever action of the lip or by auxiliary springs.

Lip Design

A good inclusion seal will allow a slight film of fluid to pass the sealing edge to lubricate the contact surface. The wiper, however, must stop all material at the sealing edge because the medium it seals is seldom lubricating and is often abrasive.

The major consideration in wiper lips is that the sealing edge be kept in intimate contact with the shaft.

The lip is normally short and sturdy — particularly for reciprocating shafts — to overcome the resistance of the foreign material. At the same time, the lip must be flexible enough to follow shaft side motion.

Wiper Materials

Seal lips are usually leather or an elastic such as polyurethane or rubber.

SCRAPERS

Exclusion seals that have a metallic lip or scraping element are called *scrapers* (Fig. 19). They are used to scrape heavy or clinging material from reciprocating shafts. Wipers are sometimes used behind them to catch any fine particles or fluids which pass the scraper.

As the shaft moves inward toward the scraper, the sharp sealing or scraping edge of the scraper element removes foreign material. The scraping edge is kept sharp by the honing action of the shaft passing through it. Sufficient contact pressure to keep the edge in intimate contact with the shaft is supplied by pre-stressed spring action of the scraper element or by auxiliary springs.

Basically, there are two types of scrapers:

- **Conical Scrapers**
- **Scraper Rings**

These two types are shown in Fig. 19.

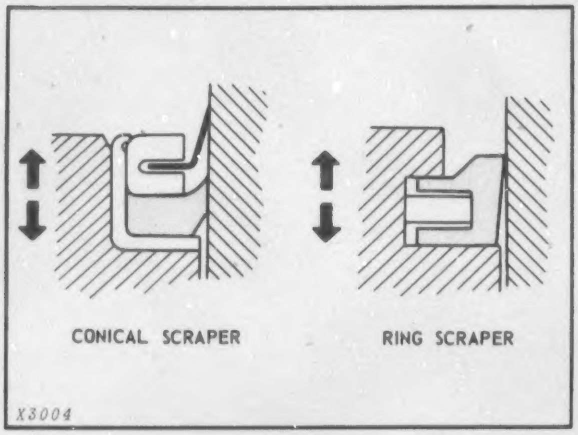


Fig. 19 — Scrapers

The CONICAL SCRAPER has a sharp knife edge which digs under the material and lifts it from the shaft.

The SCRAPER RING has a flat top as shown. Although this produces somewhat more resistance to scraping than the conical scraper, the scraping edge is quite sturdy.

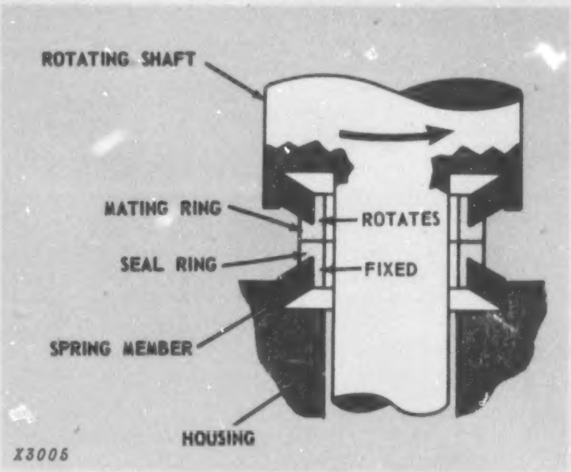


Fig. 20 — Axial Seal

AXIAL SEALS

Axial seals (Fig. 20) exert axial contact pressure to seal two flat surfaces having rotating motion with respect to each other.

Almost all axial seals are capable of exclusion and inclusion. Their use is usually confined to applications where the radial seal is inadequate.

All axial exclusion seals contain the same basic elements (Fig. 20). The seal shown could be considered as two identical mating seals.

The ring and mating parts are either both hard, or one is hard and the other soft. Contact faces of the hard rings are usually lapped to optical flatness, while those of the soft rings must only be flat enough to make good sealing contact under the available contact force. Hard rings are usually wrought, cast, or sintered metals. Soft ring faces are leather, plastic, or elastics.

BELLOWS AND BOOTS

Since boots (or bellows) are used to prevent material from entering a mechanism, they are exclusion seals.

They differ from other seals in that they have no frictional contact. The motion is absorbed by the flexing of the boot itself.

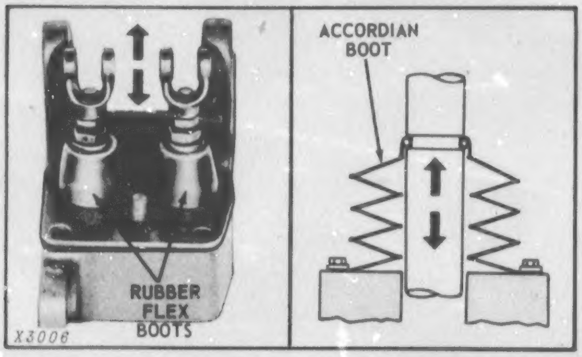


Fig. 21 — Boots Which Protect Reciprocating Shafts

Various shapes are made to cover and accommodate the motion of devices such as universal joints, ball joints, shift levers, and hinges (Fig. 21, left). These are made of sewn or cemented leather, molded elastics, or plastics.

The most common type is the accordion boot, which is used principally to seal reciprocating rods (Fig. 21, right).

MAINTENANCE OF EXCLUSION SEALS

Exclusion seals are built tough, but they will wear out early unless properly maintained.

Lubrication

Lubrication of the seal lip often is sparse. On reciprocating shafts, a slight film left by the inclusion seal is usually sufficient to prevent excessive wear and abrasion of the exclusion lip. But too thick a film will be scraped off the shaft by the exclusion lip. In rotation, the exclusion seal must depend upon seepage from the inclusion seal. Lubrication should be placed between the seals at installation. In some cases, a means of periodic lubrication is provided.

Temperature

Temperature is seldom high at the exclusion seal because it is located at the surface of the unit, where heat is rapidly dissipated.

Shaft Condition

Shaft condition is very important to life and operation of the seal. A medium shaft finish is recommended. Too fine a finish, however, will not hold sufficient surface oil film for lip lubrication, particularly if the surface is nonporous.

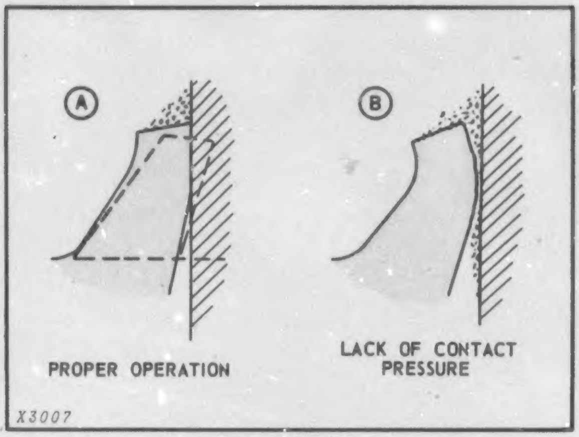


Fig. 22 — Lips Of Wiper Seals

Lip Condition

Lip condition is vital to the sealing of wipers (Fig. 22). If the lips start separating from the shaft as shown in (B), foreign material can enter and start a seal failure. The particles will scratch the shaft and wear out the seal lip. For this reason, the sealing lip must be kept in intimate contact with the shaft as shown in (A). If the lip starts to wear or weaken, replace the complete wiper.

CLEARANCE SEALS

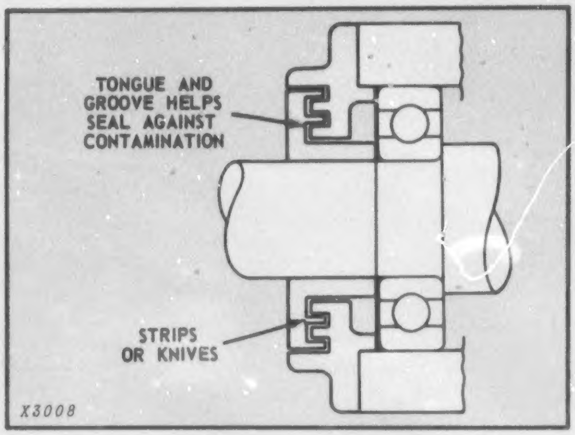


Fig. 23 — Labyrinth Seal

Clearance seals are dynamic seals which limit leakage by closely controlling the annular clearance between a rotating or reciprocating shaft and its relatively stationary housing.

The two basic types are:

- **Labyrinth**
- **Bushing (or ring)**

These seals are used when some leakage can be permitted, and pressure differentials are beyond the limits of contact seals (face and circumferential).

LABYRINTH SEALS

Labyrinth seals are used mainly in heavy industrial and power applications where relatively high leakage can be tolerated and simple design is a necessity.

A labyrinth consists of one or more thin strips or knives which are attached to either the stationary housing or the rotating shaft (Fig. 23).

Final running clearances are frequently established by contact between the knife and the housing, which rubs away or flares the knives.

Leakage of a compressible fluid is limited when the labyrinth causes the fluid to lose velocity pressure as it is throttled through the annular orifices.

Labyrinth sealing is especially effective when bearings operate in particularly dusty surroundings, as in grinding machines, and where bearings are splashed or subjected to large quantities of water as in paper-making machinery, turbines and centrifugal pumps.

Grease contributes to the efficiency of labyrinth sealing. It forms a protective layer in the housing adjacent to the labyrinth to catch any dust particles that may have penetrated the sealing device. The grooves of a labyrinth seal at assembly should be filled with a suitable sealing grease. When relubricating, grease is pressed into the labyrinth, forcing foreign particles out.

BUSHING AND RING SEALS

The bushing-type seal is a close-fitting stationary sleeve within which the shaft rotates.

Leakage from a high-pressure source at one end of the bushing to a region of low pressure at the other end is controlled by the restricted clearance between shaft and bushing.

Bushing and ring seals have a lower leakage per unit length than labyrinths.

Bushings are *fixed* or *floating* according to whether or not they are fixed with respect to the stationary housing.

RING SEALS

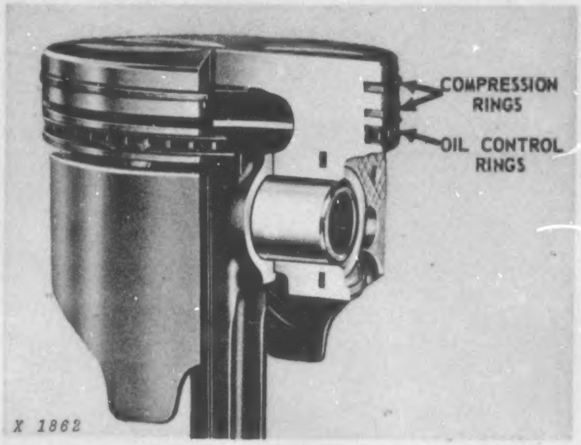


Fig. 24 — Split-Ring On An Engine Piston

Ring seals are divided into two classes:

- **Split-ring seals — for reciprocating parts**
- **Circumferential seals — for rotary parts**

Both types depend upon surface contact between the seal and the moving part, and between the seal and the stationary part to perform their function.

There are several other similarities between the two types. For instance, in spite of the difference in names, both are composed of split rings.

However, the *split-ring seals* are basically rings with a joint in each for ease of assembly. The rings on the engine piston in Fig. 24 are a good example.

The *circumferential seals* are more complicated in construction. Also, only some of the split rings require springs, while all the circumferentials use them.

Let's look at each type — first, the split ring.

SPLIT-RING SEALS

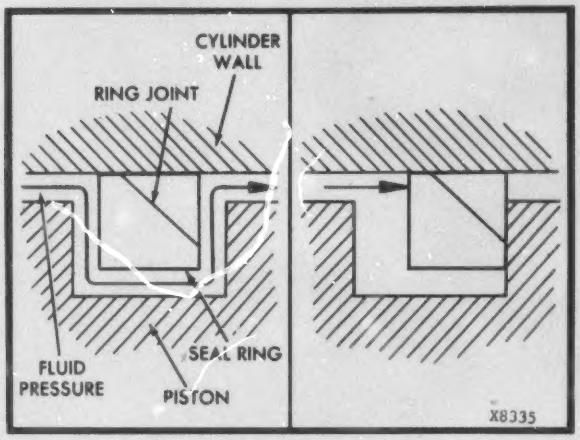


Fig. 25 — How A Split Ring Seals

Expanding split rings (piston rings) are used in compressors, pumps, and internal combustion engines.

Straight-cut and seal-joint rings are commonly used in industrial and aerospace hydraulic and pneumatic cylinders where the rugged rings are needed and leakage can be tolerated.

Contracting split rings or rod seals are used in actuators where high pressure, high temperature, radiation, thermal fatigue, and reliability prevent use of packings.

Types

Ring-type seals are primarily sealed axially by the pressure of the medium to be sealed.

There are two main surfaces against which a seal must be made: the I.D. of a cylindrical bore and the side of the piston for the expanding-type seals; and the O.D. of a rod and the side surface of a fixed housing or carrier for the contracting-type seals.

The method by which a split ring is brought into sealing position by pressure is shown in Fig. 25.
In some seals, there are extra mating surfaces or joints in the ring itself that must be sealed.

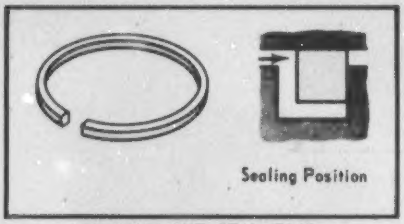
STRAIGHT-CUT SEAL RING

The simplest and least expensive type of split ring has a straight-cut joint (Fig. 26, top). Leakage through the joint is frequently of the linear type through a free passage. Hence, it depends on the gap dimensions, resistance of the passage, and the pressure and viscosity of the fluid.

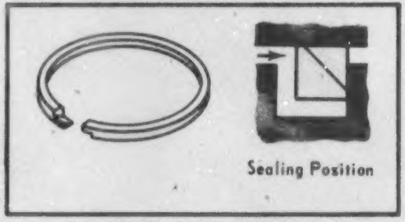
The straight-cut seal ring is used as a piston seal for lower-grade actuators. Rarely is this type of ring suitable for a rod seal.

STEP SEAL RING

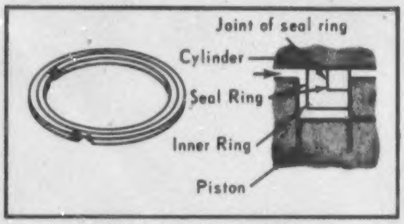
When free leakage is not permissible, a variety of types of positive sealing joints are used. The simplest of these joints is the step seal (Fig. 26, center). This seal has an overlapping surface on each half of the ring along an oblique angle. It seals simultaneously on the O.D. surface, the side surface, and the joint surface.



STRAIGHT-CUT SEAL RING



STEP SEAL RING



TWO-PIECE SEAL RING

X3010

Fig. 26 — Types Of Ring Seals

TWO-PIECE SEALING RING

To seal in both directions, a two-piece ring with a step gap may be used (Fig. 26, bottom). The joint mating surface of this ring is made perfectly flat and parallel to the side sealing face for better sealing.

Sealing in the radial direction is done by the inner member. The mating surface between these two rings, the inner and the outer, must be almost perfectly circular. For the most part, leakage in this ring is through the joint.

Pressure And Friction

For rings that must give good dynamic and static sealing, the sealing forces from hydraulic pressure must be sufficiently large in *both* radial and axial directions. This prevents hangup from friction on either the radial or the axial sealing surface.

PRESSURE BALANCING

Whenever there are heavy hydraulic pressures in a one-direction sealing ring, a good reduction in wear can be obtained by *pressure balancing*. However, balancing usually increases leakage. A circumferential groove is cut in the wear surface of the sealing member during manufacture, leaving a very thin dam which acts as a pressure reducer.

SPRING LOADING

For low-pressure sealing, garter springs are sometimes used. It may also be helpful to use axial springing of some sort, such as the wave washer under the oil control ring in Fig. 24.

Maintenance Of Split-Ring Seals (Piston Rings)

Since engine piston rings are the prime example of split-ring seals, most of our discussion will use them as an example. Almost all these maintenance problems apply to other split-ring seals as well.

Engine piston rings seal by springing out or expanding against the fixed cylinder wall as the piston moves up and down. The rings also seal against the side of the ring groove in the piston. This is mostly due to pressures in the cylinder. The rings are usually made of cast iron and are often chrome-plated on their sealing surface for longer wear life.

The main function of the piston ring is to prevent leakage of compressed fuel-air or expanding burning gases around the piston into the engine crankcase.

Another function is to limit the amount of oil for piston and ring lubrication and prevent excessive flow of oil past the piston, resulting in high oil consumption.

To do all the jobs, close tolerances at the rings must be maintained.

Inferior oils do not maintain a good film of oil between the moving parts. Consequently, there is more metal-to-metal contact and wear occurs. Then too, the thin oil film does not dissipate enough cylinder heat and is more likely to become carbonized.

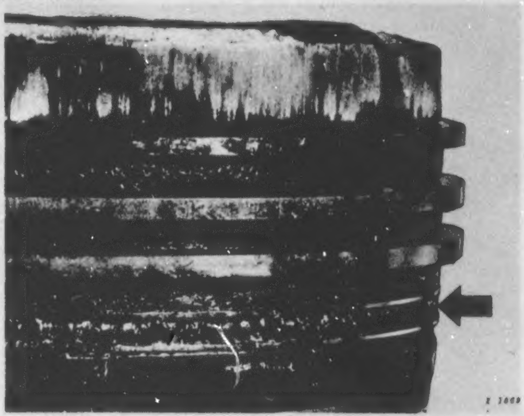


Fig. 27 — Plugged Oil Control Ring On Engine Piston

Failure to maintain proper operating temperature can also contribute to excessive ring wear or sticking (Fig. 27). Ring grooves in the piston may also wear, mostly on bottom side of groove.

Too high operating temperatures, too little coolant in the system, or obstructions in the cooling system can cause carbon to form in the ring area and cause them to stick as shown.

Failure to maintain the operating temperature high enough often leads to condensation of the fuel-air mixture in the engine cylinders. This condensate washes the lubricant from the cylinder walls, permitting metal-to-metal contact and wear. The condensate also mixes with the crankcase oil, further diluting it and reducing its lubrication.

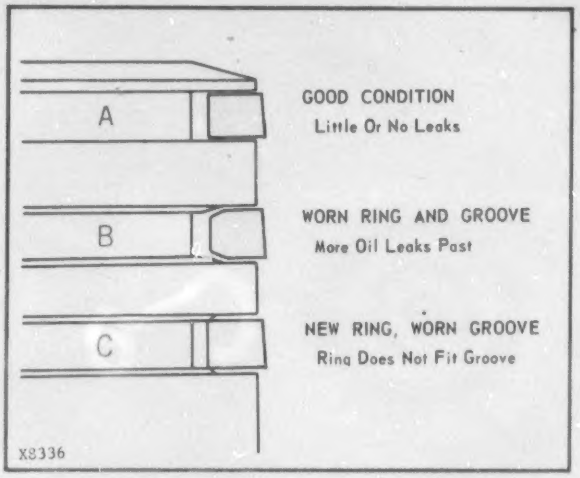


Fig. 28 — Piston Ring Grooves With Taper-Faced Rings (Schematic View)

When piston rings stick, the condition is aggravated because of blowby of the hot gases past the piston. This causes the piston to run hotter, more carbon to form in the ring area, and often causes scoring due to burning the oil off the cylinder walls.

Keystone rings are often used to help reduce sticking. Also inserted grooves help reduce wear (Fig. 29).

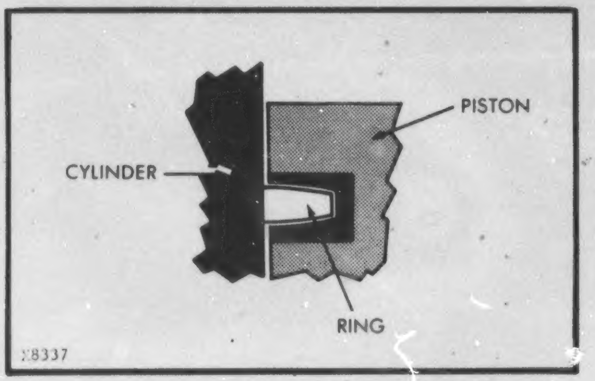


Fig. 29 — Keystone Ring With Inserted Groove

The purpose of the piston ring is to seal — not only between the ring and the cylinder wall but also between the ring and the piston.

Fig. 28 illustrates a piston with different types of ring groove conditions.

Diagram (A) illustrates the ring and groove in **new** condition. When the gases in the cylinder are compressed or expand from burning, the pressure forces the ring to seat against both the ring groove and the cylinder wall. So, if ring and groove are in good condition, little or no leakage occurs.

Incidentally, when the piston moves down on the intake stroke, the piston ring seats against the top of the groove. As the ring descends, it scrapes oil from the cylinder wall. This oil provides for lubrication and sealing of the ring.

As the piston ring wears, a wear pattern results as illustrated in (B), Fig. 28. When the ring wears, tension is reduced and the clearance in the groove is increased. As the piston moves down on the intake stroke, the increased clearance scrapes more oil from the cylinder walls and traps it behind the piston ring. When the piston moves up, this creates a "pumping" action which results in excessive oil consumption.

Diagram (C), Fig. 28 illustrates the condition when a **new** ring is installed in a **worn** groove. It is obvious that the ring cannot provide an adequate seal in the groove. This is the main reason why, when only new rings are installed, the engine may still use too much oil.

When piston ring grooves become worn, install new pistons and rings. Do **not** attempt to recondition piston ring grooves, use oversized rings, or reuse piston ring. Also inspect the condition of cylinder bore and keep parts clean during assembly.

The above methods cannot be used on all pistons. Always consult the engine Technical Manual for specific information.

NOTE: For more details on service of engine piston rings, see the FOS manual on "Engines."

INSTALLING RINGS

Take extra care when installing piston rings. Never expand them more than necessary to place them over the piston. Avoid twisting as this will distort them and prevent seating against the cylinder walls. Also inspect ring grooves to make sure they are free of nicks.

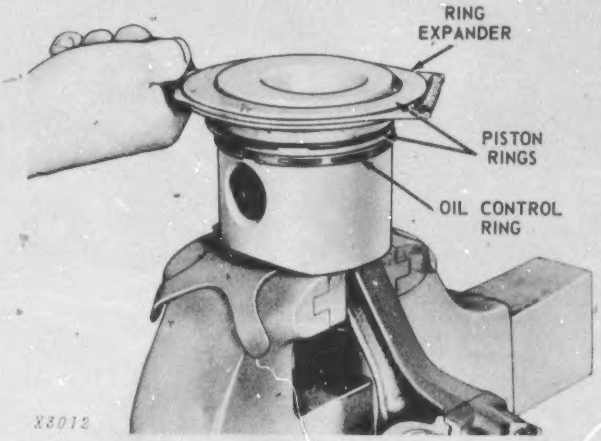


Fig. 30 — Installing Piston Rings Using A Ring Expander.

It is recommended that a piston ring expander (Fig. 30) be used to install piston rings. This expander not only prevents twisting the ring but also assures that it is expanded evenly all around, preventing distortion.

IMPORTANT: The old practice of installing piston rings by hand is definitely wrong. This method almost always distorts the rings.

Many rings in current applications are taper-faced. Make sure taper-face rings are installed correctly (Fig. 28).

Always oil the piston and rings before installation.

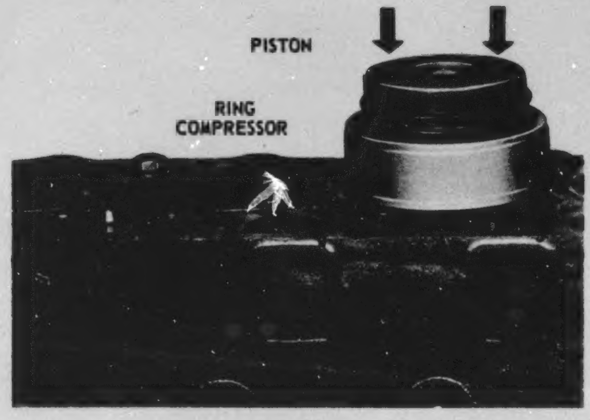


Fig. 31 — Installing Piston In Cylinder

Many types of piston ring compressors for installing pistons in the cylinders are available. However, the type illustrated in Fig. 31 is by far the most satisfactory. It has a metal sleeve with the inside tapered so that the rings are gradually compressed and easily enter the cylinder. This avoids possible burring or distortion which can occur when other types of compressors are used.

Metallic ring seals are also used in transmissions, oiling shafts and on hydraulic piston heads to prevent oil leakage where nonmetallic seals would be inadequate.

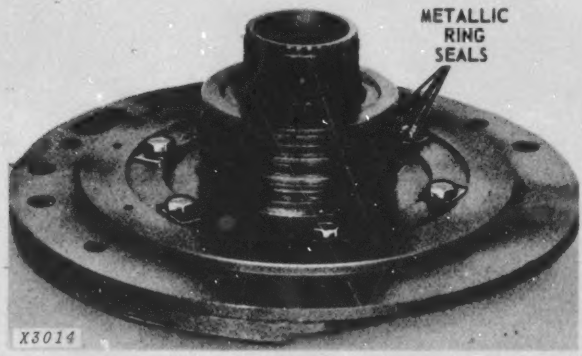


Fig. 32 — Metallic Seal Rings

Fig. 32 illustrates a typical installation of metallic sealing rings in a hydraulic transmission. The metal rings seal like engine piston rings and must be free to move in their grooves. Any burrs or sludge will restrict the movement and impair the sealing action.

Special tools should be also used to remove and install these rings. A special ring expander pliers is often recommended. The rings themselves usually have hooked ends for blind assembly.

Be careful not to expand the ring more than is necessary to install it.

Care must also be taken when installing the component that carries the sealing rings. Usually the opening is chamferred, but be careful to avoid burring the rings.

CIRCUMFERENTIAL SEALS

Circumferential seals are high-performance, low-leakage, contact-type seals for use in rotary applications.

They can accept high-velocity rubbing at their primary sealing surfaces and offer a high sealing ability. They will also take unlimited axial motion between stationary and rotating members.

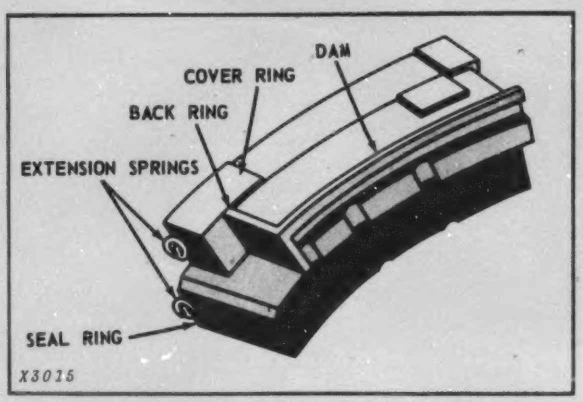


Fig. 33 — Circumferential Seal

These seals require smaller space than face seals and are lightweight.

Circumferential seals are quite similar to rod and piston seals, but are adapted to *rotary* motion. They are more complicated than regular split-ring seals and always use springs for pressure in sealing.

Basic Features

The major parts of a circumferential seal are one or more relatively stationary, flexible, split or segmented rings (Fig. 33) which mate with a rotating member. The rings are loosely keyed to the stationary member of rotation locks.

Circumferential seals prevent leakage in two directions.

Primary sealing takes place at the cylindrical surface where high-speed relative motion occurs.

Maintenance Problems

Out-of-round or taper of the primary sealing surface will result in high leakage and high wear. Moreover, as it wears, the seal ring must move radially to maintain contact. The required movement may not initially be uniform around the periphery. This creates a problem in maintaining total contact of the seal ring with the runner throughout the life of the seal.

Heat and the resulting wear can also be a problem with circumferential seals. Carbon is widely used in the sealing ring for least wear. In some high-temperature uses, cooling oil is fed to these seals during operation.

FACE SEALS

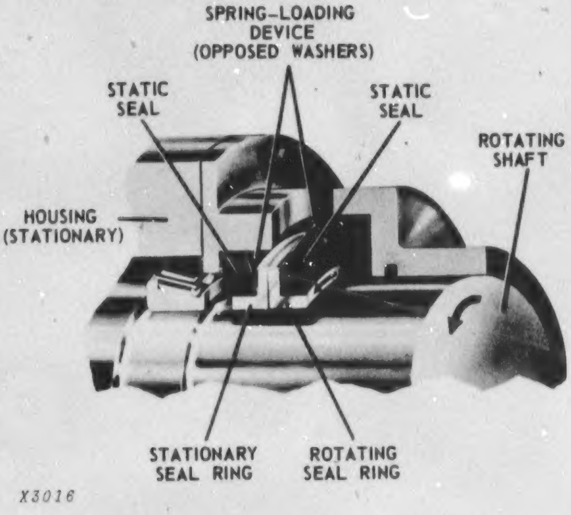


Fig. 34 — Face Seal (Axial Mechanical Seal)

The *face seal* or *axial mechanical seal* forms a running seal between flat, precision-finished surfaces (Fig. 34).

Used for rotating shafts, the sealing surfaces usually are located in a plane at a right angle to the shaft. Forces which hold the rubbing faces in contact are parallel to the shaft.

These seals replace conventional stuffing boxes where a fluid must be contained in spite of a substantial pressure head.

All face seals have the following elements.

1. **Rotating seal ring.**
2. **Stationary seal ring.**
3. **Spring-loading devices.**
4. **Static seals.**

The rotating and stationary seal ring are spring-loaded together, and sealing takes place on their rubbing surfaces. The static seal prevents leakage past the juncture of the rotating seal ring and the shaft. See Fig. 34.

Since the rotating seal ring is stationary with respect to the turning shaft, sealing at their junction is done with gaskets, O-rings, V-rings, cups, etc.

GENERAL TYPES

The main advantage of an end-face seal is its very *low leakage* rate.

The face seal also causes *little wear* of the sleeve or shaft on which it seals. Dynamic sealing is created on the seal faces in a plane vertical to the shaft and very little relative movement occurs between the seal head and the sleeve or shaft on which it functions.

In most instances, the face seal is automatically assembled into a box or set into the unit.

Standard end-face seals have been used under pressures up to 3000 psi (20 685 kPa) in heavy-duty process pumps. Special designs have been developed for pressures up to 10,000 psi (68 950 kPa). They allow for a pre-determined gap between seal faces.

Another method of handling high pressure is the tandem seal arrangement. By breaking down pressures in respective chambers, each seal faces only the resulting pressure differentials. As many tandems as necessary may be added.

MAINTENANCE OF FACE SEALS

Lubrication of the seal face must be suitable. Coking, resulting from thermal cycling, can hamper seal movement.

Face materials which *run dry* because of equipment breakdown may fail prematurely. (Some double seals with isolated liquid circulation avoid this hazard).

Abrasives can damage sealing faces if the seal is not properly lubricated and/or flushed during operation.

When installing new face seals, be sure to assemble them properly and locate them correctly using the recommended drivers.

METAL BELLOWS SEALS

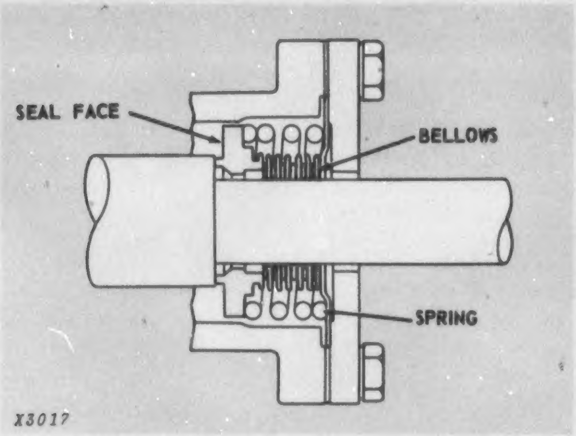


Fig. 35 — Metal Bellows Seal on Shaft

The main function of the *metal bellows* in face seals (Fig. 35) is to replace the static seal element.

Their major advantage is on special applications where an *all-metal* seal is necessary — generally for high temperatures or where the liquids or gases used would harm other seal materials.

In addition, the bellows can be used as a spring to produce the face loading needed for sealing contact between the seal faces. In some seals the bellows spring force is supplemented by a helical coil spring (Fig. 35). In others, the bellows provides all of the required spring force.

Maintenance

Metal bellows seals are built of all-metal for severe service. Properly installed and cared for, they will give long service life.

COMPRESSION PACKINGS

Compression packings create a seal when squeezed between the throat of a stuffing box and its gland.

Under these compressive forces, the packings flow outward to seal against the bore of the box and inward to seal against the moving shaft or rod.

Compression packings require frequent gland adjustment to compensate for wear.

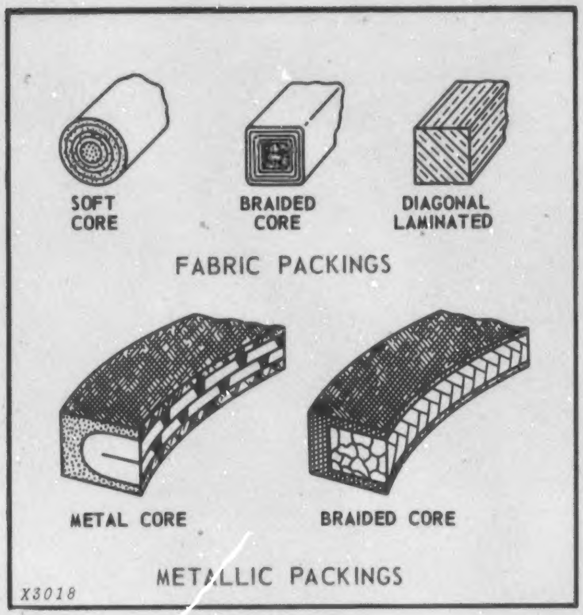


Fig. 36 — Typical Compression Packings

DESIGN

Compression-type packings are usually made square or rectangular in cross section. There are three classes of packings: **fabric, metallic**, and **plastic.**

Several types of construction (Fig. 36) are used for fabric and metallic packings to provide resilience.

The packing ring joint is important. A diagonal cut gives good overlap at the joint, and makes it possible for gland and fluid pressure to create a tight seal. It also allows the ends to slip over each other if and when the ring expands. If multiple rings are used, the joints are staggered to prevent leakage through the end cuts.

OPERATION

A packing is like a bearing — it needs lubrication.

Usually the packing is snugged up by means of the gland. In operation, the fluid flows through the slight clearance between the moving parts and the packing, and acts as a lubricant for the packing.

If the gland is overtightened, *all* leakage is stopped, causing the packing to run dry and create frictional heat.

For high temperatures or pressures, some means of external lubrication and cooling may be necessary.

SELECTION

The cross section of a packing is related to the size of the rod or shaft on which it is used. Recommended packing sizes for various shaft sizes are listed below.

Recommended Packing Sizes for Various Shaft Diameters

Shaft Diameter (Inches) (mm)	*Packing Size (Inches [mm] in Cross Section)*
1/2 to 5/8 (13-16)	5/16 (7.9)
11/16 to 1-1/2 (17.5-38)	3/8 (9.5)
1-9/16 to 2 (40-51)	7/16 (11.1)
2-1/16 to 2-1/2 (52-64)	1/2 (12.7)
2-9/16 to 3 (65-76)	9/16 (14.3)
3-1/16 to 4 (78-102)	5/8 (15.9)

If an **undersized** packing is used, it must be compressed too much to fill the packing space. This reduces the amount of compression provided for future take-up.

On the other hand, an **oversized** packing must be beaten or rolled down so that it fits in the packing space. This overloads the packing and causes it to overheat.

MAINTENANCE

Packings should be installed carefully to avoid twisting or tearing. Lubricating them is usually recommended before installation. Some are also soaked in oil or other fluid.

As with most other seals, it is a good rule to **replace all packings which are disturbed during repair of a system.** Always use the correct size of packing for replacement.

MOLDED PACKINGS

Molded packings are often called automatic, hydraulic, or mechanical packings.

These packings usually do not require gland adjustment after installation. The fluid being sealed supplies the pressure to seal the packings against the wearing surface. Molded packings are normally used for *dynamic* sealing.

There are two major types of molded packings:

- **Lip types**
- **Squeeze types**

LIP-type packings include flange, cup, U-cup, U-ring, and V-ring packings.

SQUEEZE types include O-rings and related forms, plus felt packings. All rely on interference built into the ring for effective sealing.

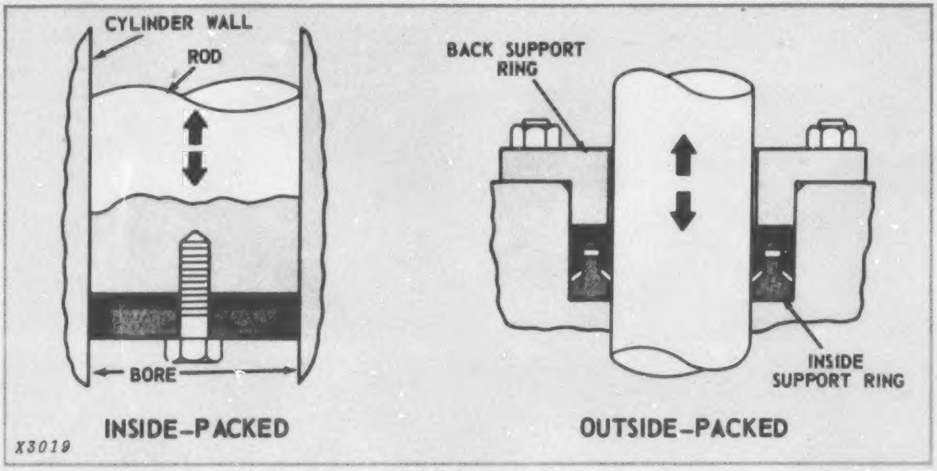


Fig. 37 — Inside and Outside-Packed Installations

LIP-TYPE PACKINGS

Lip-type packings of the flange, cup, U-cup, U-ring, and V-ring configurations are used almost exclusively for dynamic applications.

Although rotary motions are found, the packings discussed here are used primarily for sealing reciprocating parts (Fig. 37).

Lip-type packings are usually made of leather, rubber, or synthetics (often rubber-fabric mixes).

General Design

SEAL LOADING: The principle of operation for all dynamic packings is the same, regardless of type or material. A molded packing, particularly the lip type, should be installed so that it can expand and contract freely. This action is referred to as *breathing*. A molded packing should not be used under high mechanical pressure, since this in effect transforms a self-acting packing into a compression packing.

A lip-type packing is sealed by the force of the pressure being sealed, which causes the packing to expand. Friction force is produced in proportion to the pressure on the pressure stroke. If the packing is allowed to breathe, the friction on the return stroke is negligible.

Preloading is essential to ensure a tight fit for packings at low pressures. A lip-type packing, molded with a slight flare, is preloaded at the lips upon installation.

BACK SUPPORT RING: Under pressure, all packings follow the shape and contour of the back supporting components. Since the greatest wear on a packing occurs at the shoulder, proper support of the packing at its shoulder is the most vital factor in the design.

If excessive clearance exists between the cylinder wall or the shaft and the ring, operating pressure will extrude the shoulder of the packing into the clearance.

Examples of typical inside and outside dynamic packing installations are shown in Fig. 37. Recommended clearances are based on the type of material.

INSIDE SUPPORT RING: An inside support ring (if made from metal) should not have a tight fit, but should have clearance. The corners must be chamfered to prevent cutting the inside shoulder of the packing. If no clearance is provided, the packing will swell and cause binding; with clearance, the packing is free to breathe.

METALS AND FINISH: The type of metal and surface finish over which the packing operates is critical. A hard, close-grained material that will take and hold a fine finish produces the least packing friction and wear. Rods exposed to the atmosphere are normally chrome-plated. In a dirty environment, the packing and other parts are usually protected by use of a rod scraper.

BEARING AREA: Packings are designed to function as a seal and should not be subjected to any bearing loads.

CYLINDERS AND RODS: Good packing service cannot be expected from cylinders or rods which are not concentric.

SYSTEMS: A clean lubricating system is vital. Filters and rod scrapers will guard against contamination. A filter in a line will trap foreign particles, such as metal chips and dirt, and help ensure long packing life with trouble-free service.

OPERATING CONDITIONS: The packing used depends on whether it is for inside-packed or outside-packed installations. Some styles can only be used for one or the other.

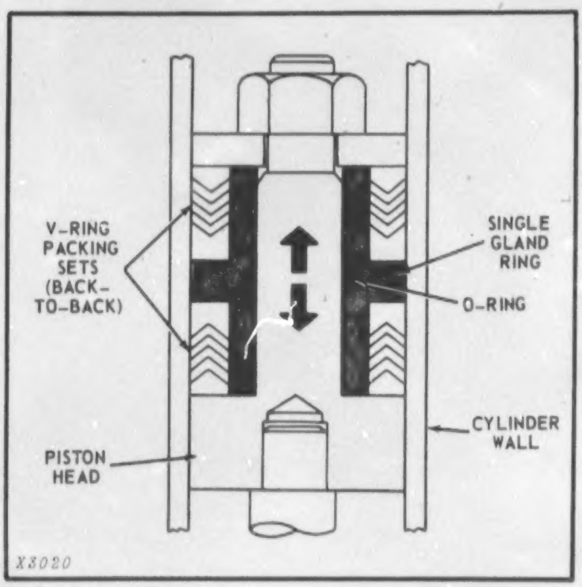


Fig. 38 — Inside-Packed Installation

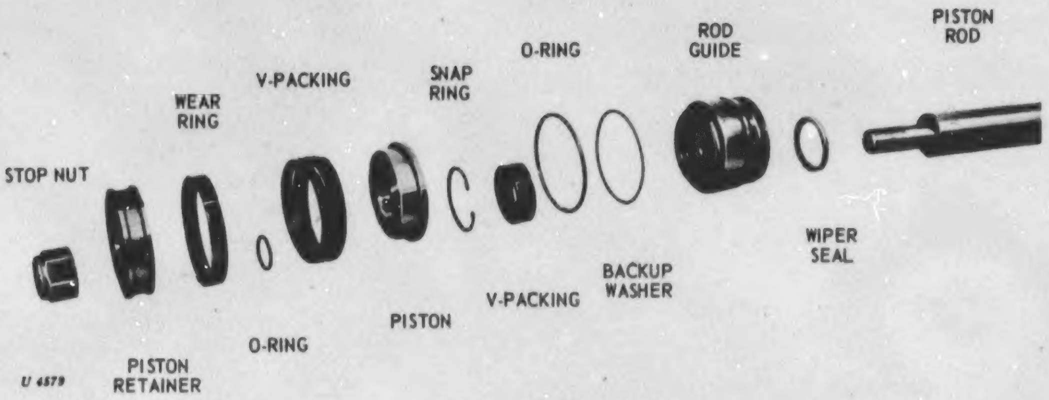


Fig. 39 — V-Packings On Double-Acting Piston Installation

In an **inside**-packed installation (Fig. 37, left), the packing is on the end of the rod or plunger and moves with the rod. The following styles can be used: cup, U-ring, and V-ring.

In an **outside**-packed installation (Fig. 37, right), the packing is in a stationary gland and the rod moves through the packing. Here the flange, U-ring, and V-ring styles are used.

No one packing style is superior to all others. Of the four styles, the cup and flange are considered unbalanced, while the U-ring and V-ring are considered balanced. (A balanced packing seals on both the O.D. and I.D. and the pressure is equalized on the side walls of the gland or recess.)

V-Ring Packings

This is one of the most popular of all the lip types, and is used for low or high-pressure applications. It can be installed on a piston (inside-packed) or in a gland (outside-packed). However, it is primarily used for outside-packed, while the U-ring is used primarily for inside-packed. V-ring packings are shown in Figs. 38 and 39.

V-ring packings are installed in sets, each set consisting of a number of V-rings (pressure rings) and a male and female adapter. The number of rings to a set depends upon the pressure and packing material.

V-ring sets are often split on an angle for easy installation. When split sets are used, the joints should be staggered on successive packings, like piston rings. Whenever possible, endless (solid) rings are used because of their better sealing and longer life.

PACKING APPLICATION: Homogeneous and most fabric V-ring packings are generally molded with the lip at a slight angle. When the packings are installed, this flare automatically preloads the packings, and only slight initial adjustment of the gland ring is necessary.

Leather V-rings do not have this flare and require slightly more initial adjustment to provide the preload.

Regardless of the material, packing sets should not be tightened excessively, but should be allowed to function as a mechanical packing. Due to their shape, they are sensitive to pressure changes. Sets of packings should not be loose in a gland or they may become cocked. Furthermore, a loose set will cause a pumping action that results in leakage during fast reversals.

Fig. 38 shows a design for a double-acting cylinder in which only one gland ring is used with two sets of packings. Another double-acting piston with V-packings is shown in Fig. 39.

SPRING LOADING: Generally, V-ring packings are not spring-loaded, since the set can be preloaded with an adjustable gland or without adjustment. However, some sets of V-ring packings are loaded with metal springs to eliminate manual tightening of the gland ring.

Cup Packings

Cup packings are widely used for hydraulic and pneumatic service at low and high pressures.
They are usually made of leather, homogeneous, or fabricated synthetic rubber.

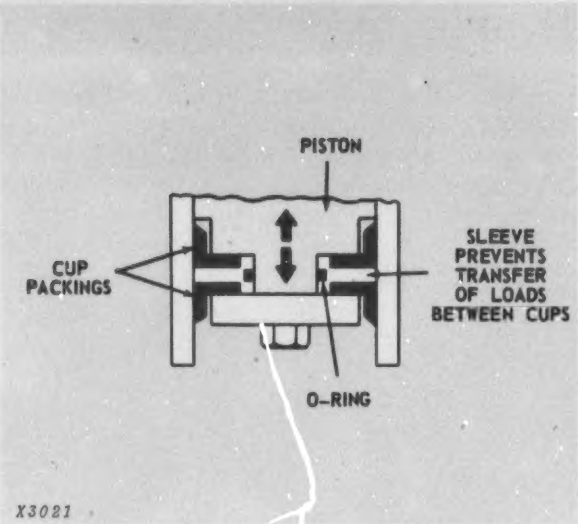


Fig. 40 — Cup Packings For Double-Acting Unit

Cups having only a single lip, as shown in Fig. 40, are classified as unbalanced packings.

Excessive tightening of the inside follower to the back follower crushes the bottom of the cup and hinders sealing.

At extremely low pressures, a cup may seal at the lip, but at higher pressures, the proper seal is not made until the heel diameter has expanded to the diameter of the cylinder wall. This causes wear to take place at the heel or shoulder of the packing. Very little wear, if any, occurs at the lip.

Resilient cup packings are preferred over hard cups except for very high pressures.

For double-acting units, a boss design is often used to prevent the transfer of load from one cup to the other (Fig. 40). The sleeve should have a close fit in the cylinder to prevent extrusion.

The lips or edges of cups are usually beveled from 15° to a maximum of 30° from the horizontal.

Cup Packing Expanders: Constant pressures, if reasonably high, will not usually require an expander for the packing. However, low and variable pressures often require expanders to exert the proper mechanical pressure on the lip of the packing. This maintains a slight preload on the cylinder or plunger.

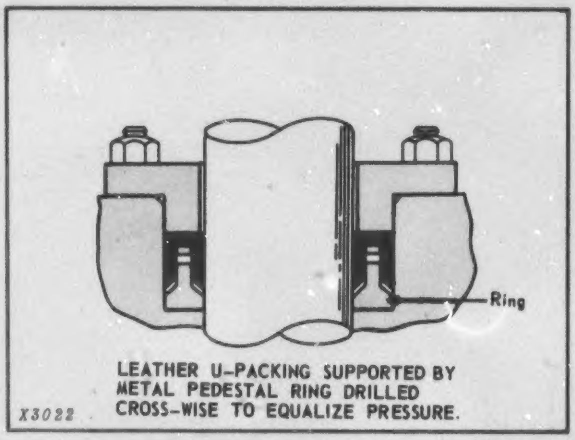

Ring
LEATHER U-PACKING SUPPORTED BY METAL PEDESTAL RING DRILLED CROSS-WISE TO EQUALIZE PRESSURE.
X3022

Fig. 41 — U-Ring Packing (Leather Type Shown)

U-Ring Packings

This packing in leather is sometimes called a "double cup"; in homogeneous, a U-cup. For both types, the correct name is *U-ring packing* (Fig. 41).

They are balanced packings which seal on both the O.D. and I.D. They have low friction and are not stacked in nested sets.

The leather U-ring is more common than the fabricated, and the method of support and the configuration varies between the two.

LEATHER TYPES: The gland and back supporting ring for leather U-ring packings are important (Fig. 41). The packing must be properly supported to keep the lips from collapsing. Leather U-ring packings are made with straight sidewalls. The recess of the U-ring is filled with flax, hemp, rubber, hard tucks, or a metal pedestal ring as shown.

Clearance is required between each side of the pedestal ring and inside walls of the packing (Fig. 41). This clearance allows for swell and eliminates binding.

FABRICATED TYPES: Unlike the leather U-ring packing, the fabricated type is molded with the bottom thicker than the side walls and the side walls molded on a flare. This flare preloads the packing upon installation, and does not require a filler or any other support in the recess of the packing.

Except for the above difference, the fabricated type is similar in operation to the leather type.

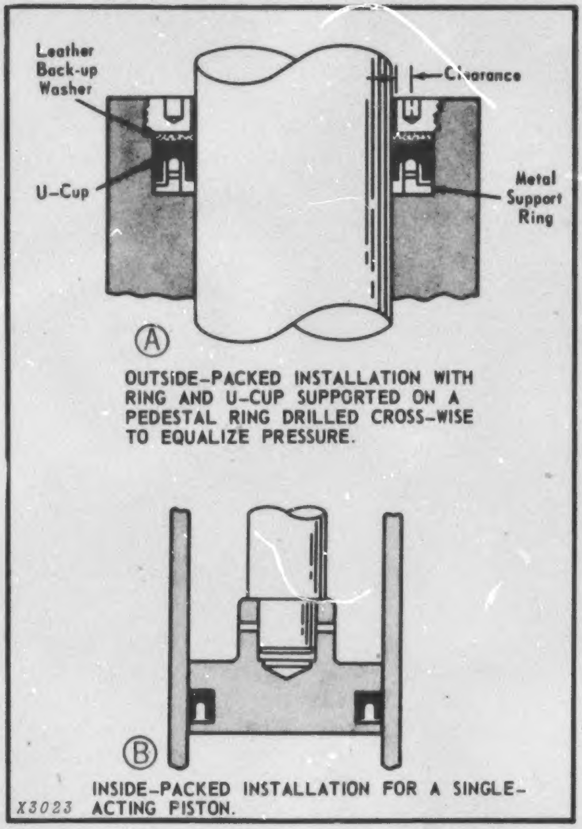

Leather Back-up Washer
Clearance
U-Cup
Metal Support Ring
A
OUTSIDE-PACKED INSTALLATION WITH RING AND U-CUP SUPPORTED ON A PEDESTAL RING DRILLED CROSS-WISE TO EQUALIZE PRESSURE.
B
INSIDE-PACKED INSTALLATION FOR A SINGLE-ACTING PISTON.
X3023

Fig. 42 — Typical U-Cup Packings

U-Cup Packings

This style of balanced packing is primarily made of homogeneous synthetic rubber, and is easily installed. It has a low friction and is primarily used for pressures under 1500 psi (10 340 kPa), although some designs are made for 5000 psi (34 475 kPa) and higher.

Typical U-cup packing designs are shown in Fig. 42.

A metal support ring is often used for *outside*-packed installations (Fig. 42, A).

For *inside*-packed installations, the metal support ring is seldom used. Fig. 42(B) shows an inside-packed installation for a single-acting piston with a U-cup stretched over the piston and snapped into place.

For a double-acting piston, an additional groove is machined and two U-cups are installed. Two U-cups are never used in the same groove. A two-piece piston is sometimes used to avoid groove cutting and consequent stretching of the U-cup during installation.

The U-cup replaces the cup packing in many installations; often it is simpler and cheaper.

Flange Packings

The flange packing — sometimes called "hat" — is the least popular of all the lip-type packings.

Primarily made of leather, it is also produced in fabricated and homogeneous materials. It is unbalanced, with sealing on the I.D. only, and is used for low-pressure, outside-packed installations where a V-ring or U-ring cannot be used due to lack of space. It is used for both reciprocating and rotary motion.

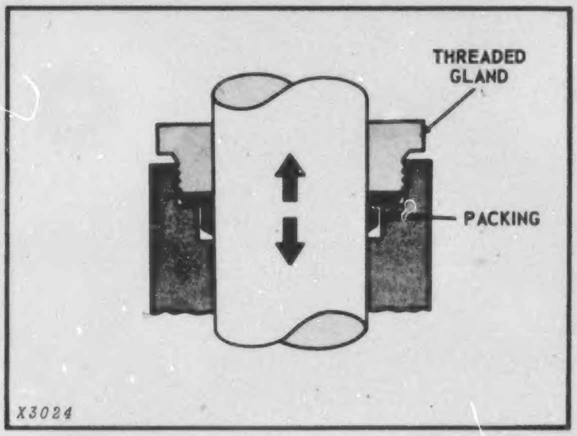

THREADED GLAND
PACKING
X3024

Fig. 43 — Flange Packings

In most installations, the flange packing is installed using a threaded gland (Fig. 43).

The packing is mechanically operated by the actuating pressure on the I.D. side wall and relies upon mechanical compression of the base for sealing the O.D. Hence, the gland ring must be drawn up tight enough to seal for the maximum operating pressure.

Clearance is required between the side wall of the packing and the cylinder body to allow for swell. There also must be clearance between the beveled lip of the packing and the bottom of the gland.

Standards have been established only for leather flange packings up to 5½-inch (140 mm). For larger rods, V-ring or U-ring packings are used.

SQUEEZE-TYPE PACKINGS

Squeeze-type molded packings are made in a variety of sizes and shapes, but nearly all of them offer these advantages: low initial cost; compact; easy to install; efficient; no adjustment; tolerate wide ranges of pressure, temperature, and fluids; seal in both directions; and relatively low friction.

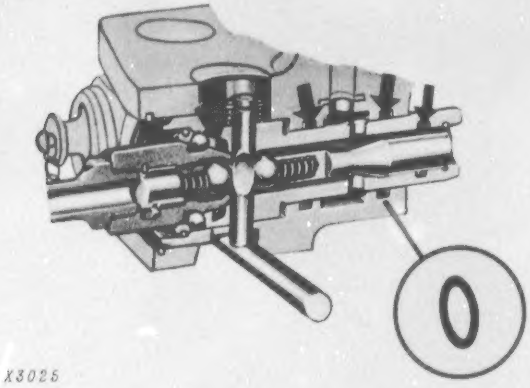
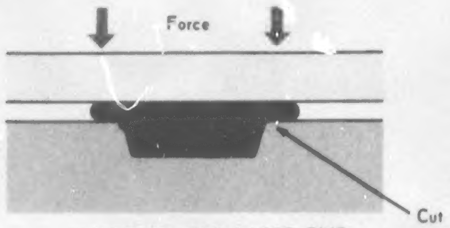


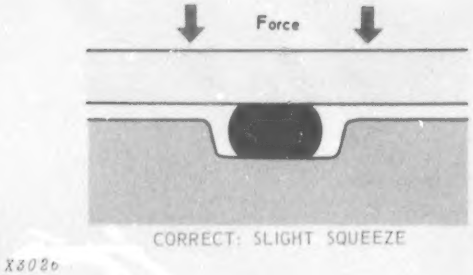
Fig. 44 — Squeeze-Type Packings (O-Rings Shown)

Squeeze-type packings are generally fitted to rectangular grooves machined in hydraulic or pneumatic mechanisms.

Since the rubber **O-ring** is the most common form of squeeze-type packing, and its application is similar to other types, this section is mainly about O-rings.



INCORRECT: TOO-LARGE RING

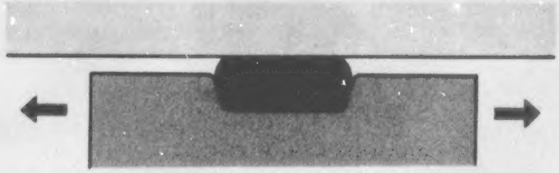


CORRECT: SLIGHT SQUEEZE

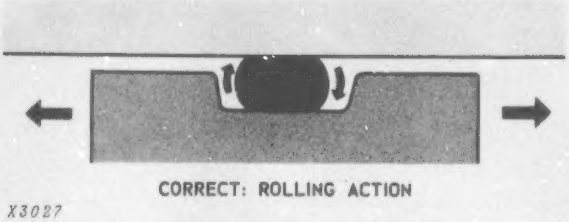
Fig. 45 – O-Ring Squeeze

Operation

O-rings work because they are *squeezed* when installed (Fig. 45). But it is the pressure from the confined fluid that produces the final deformation which causes the elastic O-ring to seal.



INCORRECT: NO ROLLING ACTION



CORRECT: ROLLING ACTION

Fig. 46 — O-Ring Rolling Action

There are three uses of dynamic O-rings:

1. **Reciprocating,** where the sealing action is that of a piston ring or a seal around a piston rod.
2. **Oscillating,** where the seal rotates back and forth through a limited number of degrees or several complete turns.
3. **Rotating,** where a shaft turns inside the I.D. of the O-ring.

Grooves for *reciprocating* motion are from 25 to 50 percent wider than the diameter of the O-ring cross-section. The O-ring then seals by rolling and sliding to the side of the groove away from the pressure. When the pressure force reverses, the ring rolls and slides to the other side of the groove (Fig. 46).

O-ring grooves are normally chamfered to avoid cutting the O-rings.

Applications

Squeeze-type packings are economical and easy to install. One common application of an O-ring is as a piston seal in a hydraulic actuating cylinder. Another uses the O-ring as a valve seat or as a valve plug packing (Fig. 44).

O-rings are **not** used: (1) in very dirty or abrasive conditions; (2) where lubrication is sparse; (3) at very high shaft speeds.

Back-up rings are sometimes used with O-rings to prevent "nibbling" and other damage in operation.

Maintenance Of O-Rings

O-rings can be easily damaged by cutting or nicks from sharp objects. They can also be damaged by heat, wrong fluids, lack of lubrication, and improper installation. See Fig. 47 below.

INSTALLATION OF O-RINGS

1. Be sure the new O-ring is compatible with the hydraulic fluid. Otherwise, the O-ring may corrode, crack, or swell in operation.

2. Clean the entire area of all dirt and grit before installing O-rings.

3. Inspect O-ring grooves before installing rings. Remove any sharp edges, nicks, or burrs with a fine abrasive stone. Then reclean the area to remove any metal particles.

4. Inspect the shaft or spool (if used). Sharp edges or splines can cut O-rings. Remove any nicks or burrs with a *fine* abrasive stone. Then polish with a *fine* abrasive cloth. Reclean the area to remove any metal particles.

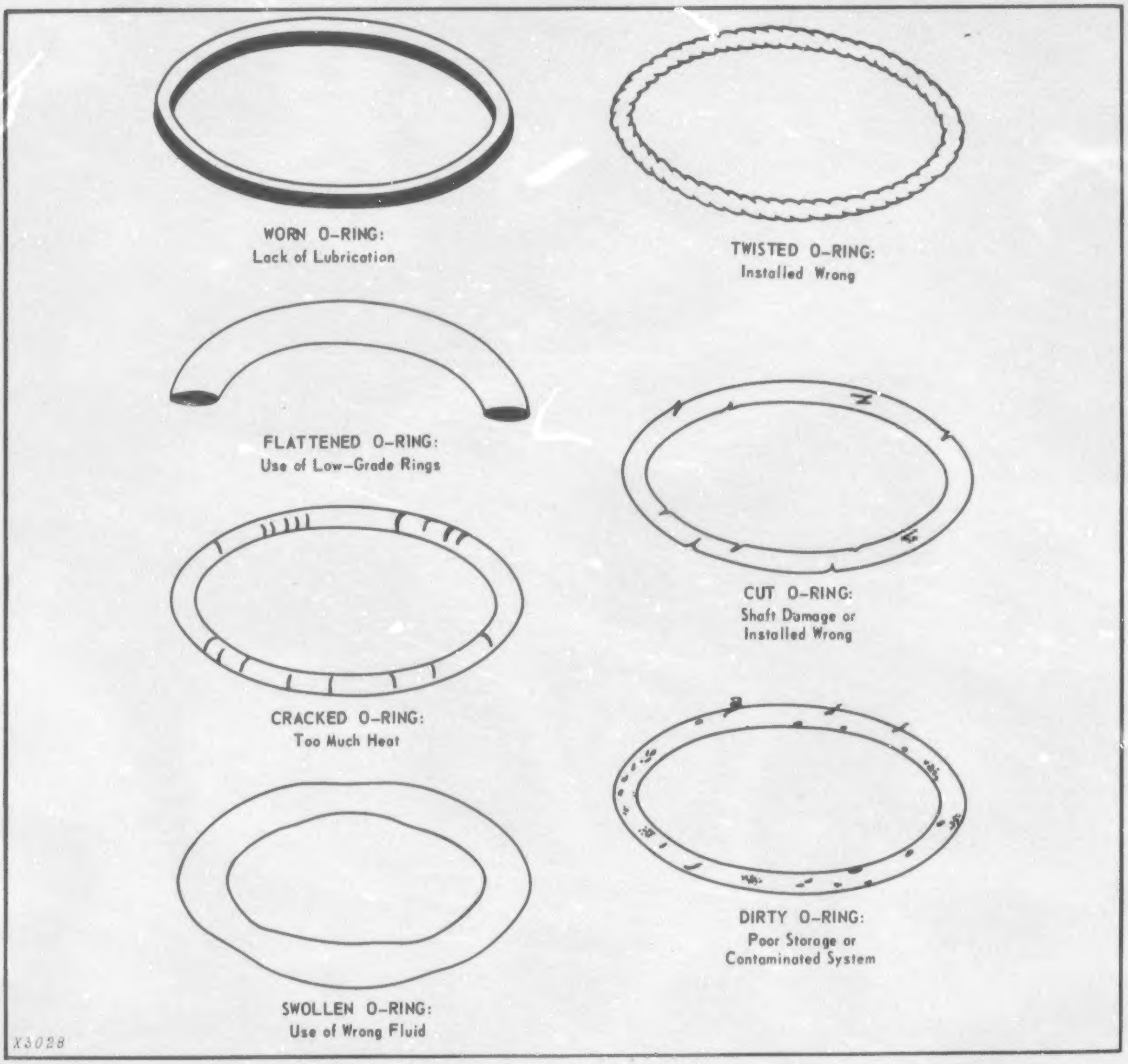

WORN O-RING:
Lack of Lubrication
TWISTED O-RING:
Installed Wrong
FLATTENED O-RING:
Use of Low-Grade Rings
CUT O-RING:
Shaft Damage or
Installed Wrong
CRACKED O-RING:
Too Much Heat
DIRTY O-RING:
Poor Storage or
Contaminated System
SWOLLEN O-RING:
Use of Wrong Fluid
X3028

Fig. 47 — O-Ring Failures

5. Lubricate the O-ring before installing it. Use the same fluid as used in the system. Also moisten the groove and shaft using the system fluid.

NOTE: Some O-rings are identified by paint slashes. This tells that the O-ring has a special use — will resist certain temperature or fluids. Be sure to match new O-rings with ones which are being replaced.

6. Install the O-ring, protecting it from sharp edges or openings. Be careful not to stretch it more than necessary.

7. Align the parts accurately before mating to avoid twisting or damage to the ring.

8. Check to see that the O-ring is of the correct size to give only a slight "squeeze" in the installed position (Fig. 46). In dynamic use, the O-ring should be able to roll in its groove.

IMPORTANT: When installing spool valves, and similar parts, be especially careful of any O-rings. The sharp edges of the lands can cut the O-rings unless you are very careful.

CHECKING O-RINGS AFTER INSTALLATION

Dynamic O-rings should be cycled (moved back and forth through their normal pattern of travel) several times to allow the ring to rotate and assume a neutral position.

All dynamic rings should pass a very small amount of fluid when rotating, which permits a lubricating film to pass between the ring and the shaft. This film prevents scuffing of the ring.

NOTE: Static O-rings are covered later in this section.

FELT RADIAL PACKINGS

Felt is a built-up fabric made by interlocking fibers of wool which are used alone or combined with animal, vegetable, and synthetic fibers.

Uses

Here are some reasons why felt is used as a sealing material:

1. *Oil Wicking:* Capillary properties of a felt seal assure lubrication after long idle periods.

2. *Oil Absorption:* About 78% of the volume of a felt seal serves as oil storage.

3. *Filtration:* Wool felt seals, in a dry state, are 99 to 100 percent effective as filters in removing small particles. When saturated in lubricants, even smaller particles are trapped and retained.

4. *Resiliency:* Felt seals maintain constant sealing pressure in spite of wear, end play, minor misalignment, or out-of-roundness of metal components.

5. *Polishing Action:* Felt seals trap abrasive particles, which then penetrate into the felt. Thus, they protect surfaces by polishing them, rather than scoring them.

Types

Felt seals are manufactured in two general types:

- *Plain*
- *Laminated*

To meet special requirements, either style can be impregnated with one of several materials.

Plain felt seals are precision-cut washers fabricated from standard grades of felt. They are usually presaturated with lubricants of slightly greater viscosity than that used in the bearing. Plain felt seals afford positive bearing protection and provide a reservoir for lubricant storage — making it available as needed. If run dry, they protect and polish rather than score a shaft. They seldom fail through aging or disintegration. These seals are not used with oils of low viscosity or to retain pressurized lubricants. For these applications, laminated or impregnated felt should be considered.

Laminated felt seals are made by combining one or more grades of felt with layers of impervious elastic. This permits use of two or more felt grades or densities in one seal; one grade for oil retention and a second for dust exclusion. The impervious layers of oil-resistant elastic also stop leakage of low-viscosity fluids through the felt.

Maintenance

Normally replace felt seals when a system is overhauled.

Be sure the seal is lubricated and avoid stretching it too much when installing over a shaft.

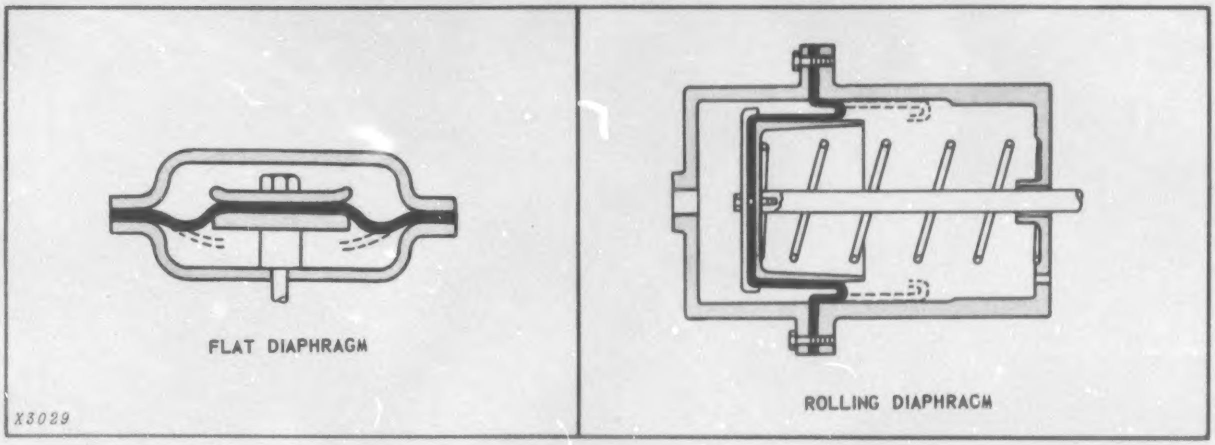


Fig. 48 — Diaphragm Seals — Two Types

DIAPHRAGM SEALS

A **diaphragm** is a dividing membrane which spans the gap between a moving and stationary member. As a seal, it prevents interchange of a fluid or contaminant between two separated areas or chambers.

Diaphragms can be divided into three types:

1. One type acts solely as a **separating membrane** *where no pressure differential exists between the chambers.*

2. A **static diaphragm** *acts as a separator between two fluids and is subject to little or no motion.*

3. A **dynamic diaphragm** *acts as a sealing device between stationary and moving members, and usually transmits a force or pressure.*

The diaphragm used as a *dynamic* sealing membrane and force transmitter is the most common type and the main part of this section is devoted to it. This diaphragm acts in the same way as a sliding-contact packing, except for no leakage.

Dynamic diaphgrams are of two types:

- **Flat**
- **Rolling**

A FLAT diaphragm (Fig. 48) is one which has no convolutions, or convolutions which are less than 180°.

A ROLLING diaphragm (Fig. 48) has a full 180° convolution; during its cycle the diaphragm rolls off the wall of the cylinder or piston onto the other cylinder or piston wall.

FLAT AND CONVOLUTED DIAPHGRAMS

"Flat" diaphragms are not necessarily flat. Even when a diaphragm is made flat, convolutions are formed by fluid pressure during the working cycle. Also, diaphragms which are made flat are distorted when there is relative movement of the diaphragm assembly (Fig. 48, left). This distortion requires an elongation of the cord length of the fabric. For this reason, flat diaphragms are generally made of a flexible material. This allows the diaphragm to flex rather than stretch.

Diaphragms are usually made of fabric, impregnated with an elastic. Most combinations can withstand flexing indefinitely, but stretching can cause fatigue failures.

Diaphragms are attached to the housings at the edges, while the center is usually held with plates. A *push rod,* attached to the center plates and guided by the housing, transfers motion to the diaphragm, or is moved by pressure behind the diaphragm, See Fig. 48, left.

Springs are usually used in conjunction with diaphragms to provide a return or to provide a reference force for pressure regulation.

For each application, there is a correct "squeeze" or precompression which provides adequate sealing without undue distortion of shape.

ROLLING DIAPHRAGMS

Rolling diaphragms are used as if they were long-travel bellows, or radially-sealed hydraulic pistons with zero leakage. See Fig. 48, right.

Operation

The rolling diaphragm has a full 180° roll in operation. When pressure increases in the loading chamber, the piston moves down, causing the diaphragm to roll off the piston sidewall and onto the cylinder wall with a frictionless action (see Fig. 48, right). Almost the entire pressure load is supported by the piston head, and only a small load is felt by the diaphragm. Contained pressure holds the rolling diaphragm against the walls.

Rolling diaphragms can be used in many medium- and high-pressure applications.

However, rolling diaphragms cannot be used where the normally low-pressure side exceeds, at any instant of time, the pressure on the normally high-pressure side by more than ½ psi (3.4 kPa). This pressure reversal may cause sidewall distortion, overstressing, and scuffing.

STATIC SEALS

In this section we will cover all the **static** seals listed in the box on page 44.

NONMETALLIC GASKETS

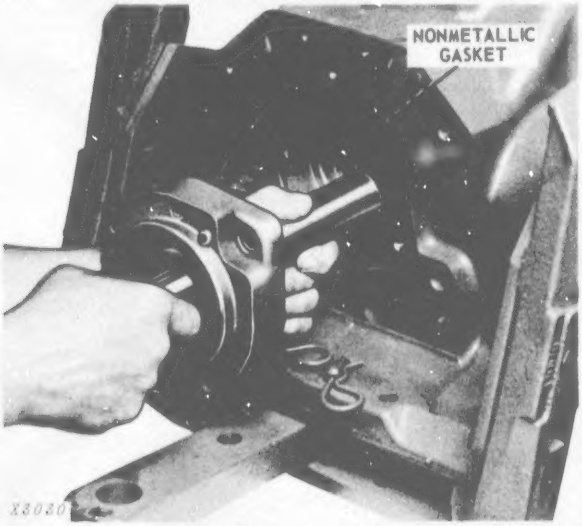


Fig. 49 — Nonmetallic Gasket In Low-Pressure Application

Gaskets are **static** seals. A gasket is any device which maintains a barrier against the transfer of fluids across mating surfaces of a mechanical assembly *when the surfaces do not move relative to each other.*

Joint and gasket design must be considered together. A joint is only as good as its gasket, and the gasket may succeed or fail according to whether the joint makes the best use of the gasket material. Therefore, joint components must be thought of as a unit, or system, for effecting a seal. Otherwise, the end result may be a leaky joint.

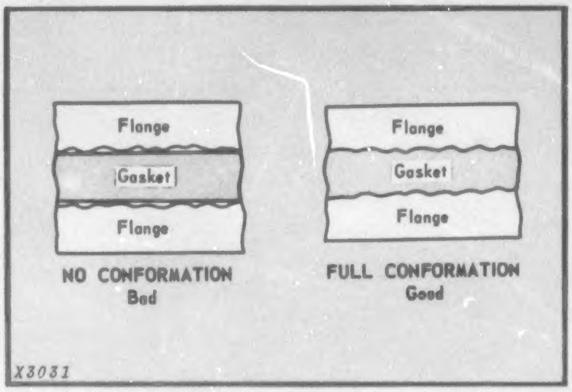


Fig. 50 — Conformation Of Gasket To Flange

A prime factor in any seal or gaset is *minimum sealing stress.* This is the minimum stress necessary to make the seal material conform to the imperfections on the flange face (Fig. 50) and, where necessary, to close the material's porous structure so leakage does not occur.

JOINT AND GASKET DESIGN

The minimum stress required for sealing a gasket depends on:

- **Gasket material**
- **Internal pressure**
- **Sealed fluid**
- **Width-to-thickness ratio of gasket**
- **Gasket shape factor**
- **Flange finish**

Gasket Material. Minimum sealing depends greatly on the type of material used in the gasket. Common materials are: asbestos, cork, rubber, plastic sand paper, or combinations of these.

Internal Pressure. Internal pressure tends to force the sealed fluid through the seal assembly; thus, it has a vital effect on how much initial flange pressure is necessary to seal the joint.

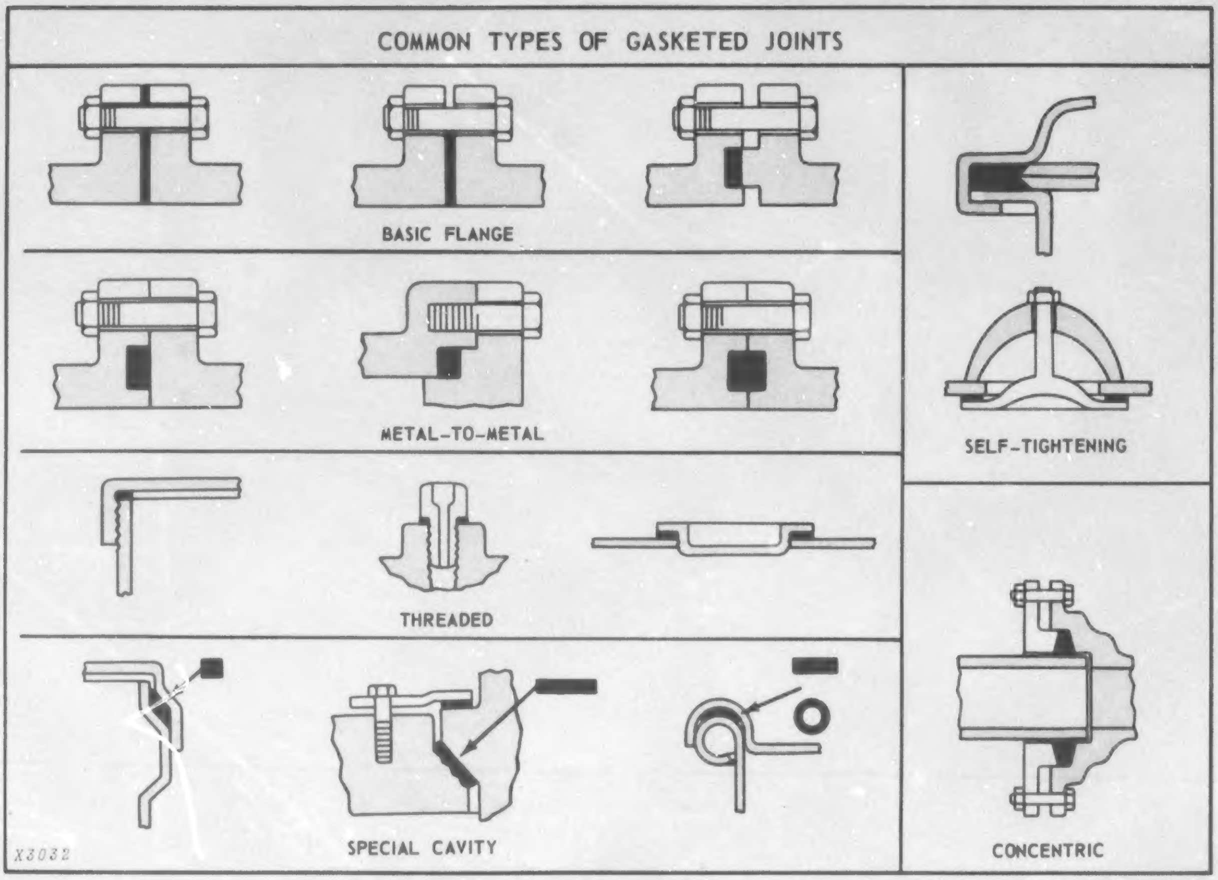


Fig. 51 — Common Types Of Gasketed Joints

Sealed Fluid. Except for certain materials — like cork-and-rubber — the sealed fluid affects the required minimum sealing stress. Most important here is the type and vicosity of the fluid.

Width/Thickness Ratio. Minimum sealing stress decreases as the ratio of sealing width of a gasket to its uncompressed thickness increases. This is especially significant in gaskets which have bolt holes. In such cases, the holes must not be too close to the inner edge of the gasket.

Shape Factor. A satisfactory seal requires minimum sealing stress *and* uniform gasket compression. The most important factor for meeting both requirements at once is the shape of the gasket.

Shape factor has no effect on the load compression of cork composition, but a significant effect on rubber. The more compressible the material, the less effect shape has on its load compression, since loading does not cause as much lateral expansion.

Flange Finish. Flange surface finish is not an important factor with compressible gaskets because they conform readily to minor irregularities. However, harder materials may not deform enough to seal rough finishes.

In general, a gasket must be impermeable to fluids, flow into imperfections when compressed, seal through variable temperatures and pressures, and resist deterioration.

Common types of gasketed joints are shown in Fig. 51.

MAINTENANCE PROBLEMS WITH GASKETS

Below we will discuss some common problems with gaskets and gasketed joints.

Joint Distortion

Distortion of gasketed joints usually causes a nonuniform pressure distribution over the gasket. Joint distortion exists whenever the flange faces are not parallel and/or the bolts are deformed other than that caused by normal tightening.

Six types of joint distortions can occur. The first three — *flange bowing, bolt hole distortion,* and *cocking* — are caused by the effect of bolt loads on a flexible flange. The fourth is caused by *flange surface roughness.* The last two are caused by *excessive internal pressure.* Distortions normally occur in combinations.

Flange Distortion: This can cause leakage at points where compression is too low for sealing. It can also cause gasket failure by extrusion or rupture where flange pressure is concentrated — for example, at bolt holes.

Flange Bowing: Even in relatively rigid flanges, bolt loads cause a certain amount of bending in the flange between bolt centers. Flange bowing almost invariably causes leakage through the low-compression regions between bolt centers. In field assembly, a full and proper torquing of all bolts will help prevent flange bowing (see "Engine Cylinder Head Gaskets," later).

Bolt Hole Distortion: Such distortion occurs around the bolt hole in a flange, most often in sheet metal flanges. It normally is a bowing effect. Causes are overtightening screws or not using proper washers.

Flange Face Roughness: Surface roughness can cause leakage if the gasket is hard and compressive loads are inadequate because of bowing or some other factor. Leakage caused by surface roughness can usually be reduced by the proper seal and the right torque.

Distortion From Internal Pressure: Internal pressure adds to the loading on bolts and flanges. Excessive internal pressure can cause bolt elongation, add to flange bowing, and cause gasket blowout.

In rigid joints, internal pressure normally causes leakage or blowout. In assemblies where the flanges distort, pressure causes the flange to lift off the gasket, resulting in leakage.

In the field, these gasket leaks or blowouts can usually be prevented by proper torquing of bolts holding the gasket.

Torque Loss

Just as important as creating the initial seal, is maintaining it throughout the life of the assembly. As soon as bolts have been tightened, various factors go to work to loosen or destroy the seal.

Bolt torques or flange pressures begin to drop because the gasket takes a "set." Mechanical vibrations may also contribute, and temperatures may rise. Finally, the sealed fluid begins to interact with the gasket.

Watch several factors to help reduce torque loss in the field: *initial flange pressure* and *bolt length; bolt diameter; temperature; time; retorquing; gasket material and thickness; sealing surface conditions.*

Initial Flange Pressure: Because initial flange pressure interacts with bolt length, the two are discussed together. In a gasketed joint, initial flange pressure is that attained immediately after the bolts are tightened; bolt length is taken as effective bolt length — which includes the flange, washer, and compressed thickness of the gasket.

At low initial torque, bolt length has no effect. As initial torque increases, however, bolt length begins to have a measurable effect.

For this reason, bolts are tightened to their maximum elongation *below* the yield point.

Bolt Diameter: The smaller the diameter, the greater the bolt elongation for a given torque. As long as yield tension is not reached, this gives better torque retention. Also, the higher the torque, the more equally the total load is distributed among the bolts.

Temperature And Time: Torque loss increases with temperature. Time also works against holding the torque. Torque loss is most rapid immediately after tightening, with most loss occurring within 18 hours. Beyond that point, torque loss proceeds indefinitely, but very slowly.

Retorquing: To guard against torque loss during service, retorquing is often helpful. This is done by tightening the assembly, warming it up at a constant temperature for a given time, and then retorquing to the initial torque. This reduces torque loss significantly (see "Engine Cylinder Head Gaskets," later).

Gasket: The gasket material has a considerable effect on torque retention. Various materials are rated in the following order: asbestos fiber-rubber, cellulose fiber-rubber, cork-and-rubber, cork composition, rubber.

Uncompressed gasket thickness also has a marked effect. Normally, the thinner the gasket, the better the torque retention up to the point where sealing is no longer adequate.

Sealing Surfaces: Any coating on gasket or flange sealing surfaces contributes to torque loss. This includes lubricants, uncured adhesives, or contaminants. Anything more than a thin film causes some torque loss.

Litho in U.S.A.

Temperature Effects

In any seal, temperature always interacts with other factors. In addition to torque loss, temperature affects relative motion of the flanges, as well as chemical interaction between the sealed fluid and gasket.

As temperature rises beyond that at which the joint was tightened, seal efficiency usually improves; this is probably due to softening of the gasket, which then "flows" into surface irregularities in the flange.

However, prolonged exposure to high temperatures causes hardening of the gasket material. Normally, this does not harm the seal because it occurs after the seal has been created. However, above the normal temperature limits the gasket begins to deteriorate.

STATIC O-RINGS (NONMETALLIC)

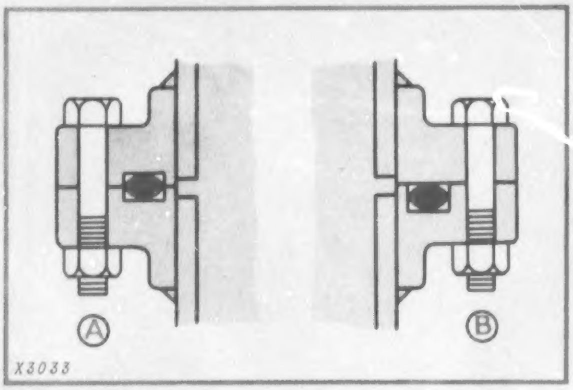


Fig. 52 — Nonmetallic Static O-Rings In Flange Joints (Two Types Of Rectangular Grooves Shown)

Static O-ring seals are classified as gasket-type seals but are in a class by themselves in terms of design and usage. See Fig. 52.

Static O-rings are generally easier to design into a unit than dynamic ones. Wider tolerances and rougher suface finishes are allowed on metal mating members. The amount of squeeze applied to the O-ring cross section can also be increased.

Static O-rings may shred or became nibbled or breded. Hence, contamination of filters and clogging of pumps are possible. No periodic tightening of nuts is necessary to maintain a tight joint. Once an O-ring is installed, operating pressure keeps it sealed against the metal clearance areas.

A rectangular groove is the most common one used for O-rings used as flange gaskets. The groove is machined one-half in the face plate and one-half in the flange, or the entire groove is cut in one member (Fig. 52).

METALLIC GASKETS

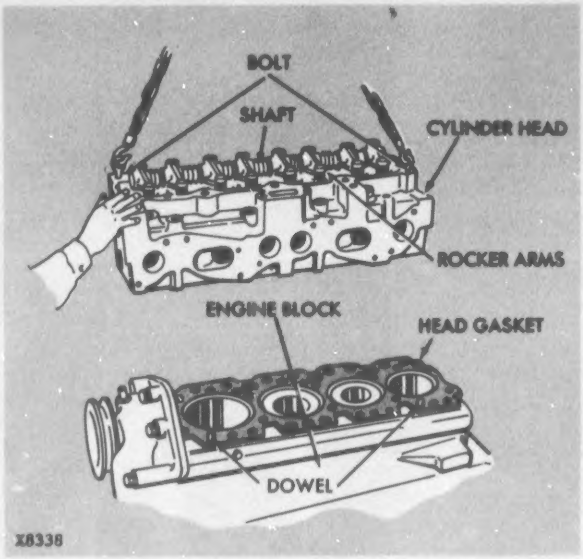


Fig. 53 — Metallic (Combination) Gasket On Engine Cylinder Head

Gaskets are softer than their mating surfaces and seal by conforming to the surface irregularities. However, two major kinds of gaskets are needed:

- **Nonmetallic gaskets — softer, for lower pressures**
- **Metallic gaskets — harder, for higher pressures and temperatures.**

We covered nonmetallic gaskets in the preceding section. Now we will give details on metallic and combination gaskets.

GENERAL TYPES

Choice of a gasket material depends on operating conditions, mechanical features of the flanged assembly, and gasket characteristics.

In general, operating conditions govern choice of gasket **materials,** while features of the flange decide selection of the **type** of gasket.

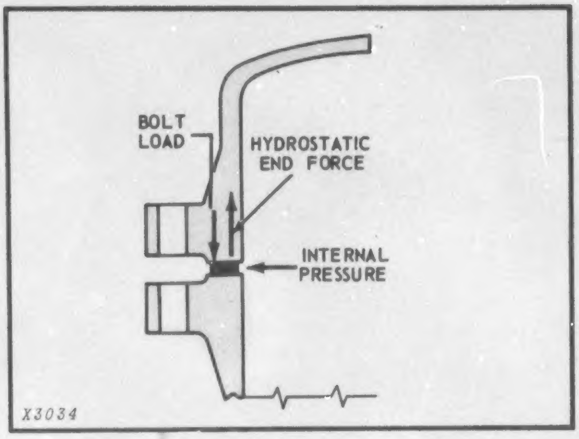


Fig. 54 — Forces Acting On Gasketed Joint

How Metal Gaskets Are Selected

Pressure: Pressure of the confined fluid has little or no direct effect upon the selection of most types of metal gaskets. One exception is corrugated gaskets, which are generally limited to pressures less than 1000 psi (6895 kPa).

Temperature: Operating temperature is important in selection of the gasket type and material. The limitation of semimetallic gaskets is controlled by the nonmetallic filler. For example, an asbestos filler normally restricts the long-term use of the gasket to 850 to 900°F (455 to 483°C), although the metallic portion might have a much higher limit.

Joint clamping: Bolting must provide enough force to seat the gasket and to prevent flange separation due to the confined fluid pressure (Fig. 54).

Joint rigidity: This must be considered because metallic gaskets usually take a permanent set when compressed in an assembly. Unlike nonmetallic gaskets, they have little or no recovery to compensate for contact face separation. Therefore, joints for which metal gaskets must be rigid to assure a minimum of bending both during the initial bolting and when the assembly is operating. Flanges using full-face gaskets must be thick enough to prevent bowing between adjacent bolts.

Surface finish: This is important in that each type of metallic gasket performs best when the flange contact faces have a specific surface finish. A problem with some high-pressure head gaskets is that the metal finish can be *too smooth,* causing the gasket to be pushed out by the pressure.

Corrosion: There are several different kinds of corrosion, and metallic gaskets are susceptible to most of them. Chemical resistance must often be built into the gasket material.

Seating Stress

Gasket sealing is done by flow of the gasket material into the imperfections on the flange facings. The amount of force per unit of gasket area required to completely flow the gasket is known as the *yield* or *seating stress.* This stress varies with gasket type, material, and flange surface finish.

Gasket Types

Metallic gaskets (Fig. 55) fall into several basic groups:

- *Corrugated or embossed, thin metal*
- *Metal-jacketed, soft filler*
- *Spiral-wound*
- *Plain or machined flat metal*
- *Round cross section, solid metal*
- *Heavy cross section, solid metal*
- *Light cross section, pressure-actuated*

Corrugated: This type (Fig. 55) consists of thin metal, corugated or with embossed concentric rings. They are used plain, coated at the time of installation with gasket compound, or with asbestos cord cemented in the corrugations.

Corrugated gaskets are essentially a line-contact seal. Multiple, concentric corrugations provide a labyrinth effect, along with mechanical support for the gasket compound or asbestos-cord inserts, if they are used. Corrugations provide some resilience, depending on their pitch and depth, and the type and thickness of metal used.

Metal-Jacketed, Soft Filler: A soft compressible filler is partially or wholly encased in a metal jacket (Fig. 55). These gaskets are more compressible than corrugated types. They offer better compensation for flange irregularities when higher pressures are to be sealed.

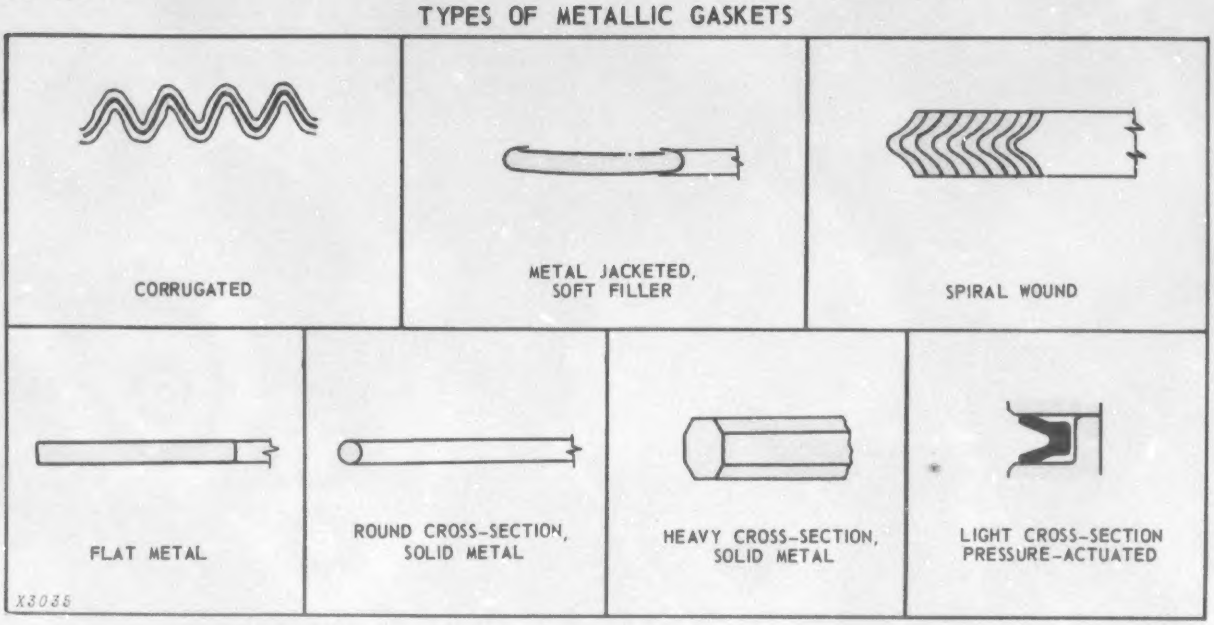

TYPES OF METALLIC GASKETS
CORRUGATED
METAL JACKETED, SOFT FILLER
SPIRAL WOUND
FLAT METAL
ROUND CROSS-SECTION, SOLID METAL
HEAVY CROSS-SECTION, SOLID METAL
LIGHT CROSS-SECTION PRESSURE-ACTUATED
X3035

Fig. 55 — Types Of Metallic Gaskets

The primary seal against leakage is the inner metal lap, where the gasket is thickest when compressed. This area cold flows, completing the seal. The entire inner lap must be under compression. The outer lap (if used) provides a secondary seal between flange faces when compressed.

These gaskets are used for noncircular as well as circular applications, and require 20 to 30% compression. They are widely used for engine cylinder heads (see later in this section).

Because of limited resilience, these gaskets are used only where the elasticity of the bolts or other factors can compensate for joint relaxation. They are not used in joints requiring close maintenance of the compressed thickness.

Standard filler is asbestos millboard. Compressed asbestos sheet packing is used where higher strength is necessary. Metallic fillers are used when service temperatures exceed 900°F. (483°C).

Spiral-Wound Gaskets: This type (Fig. 55) consists of V-shaped, performed plies of metal, wound up in a spiral with a soft separation, such as asbestos paper. The V-shape gives unique spring-like characteristics.

These gaskets have the best resilience of all metal and asbestos-type gaskets.

Sealing action results from the flow of the metal and soft filler plies when the gasket is compressed the recommended amount. Both inner and outer metal-to-metal plies must be under compression. Spiral-wound gaskets are particularly suited for assemblies subject to extremes in joint relaxation, temperature or pressure cycling, shock, or vibration.

Flat Metal Gaskets: These are gaskets that are relatively thin compared to their widths. They can be used as cut from sheet metal, or machined.

Plain metal, washer-shaped gaskets also perform satisfactorily in applications over a wide temperature range.

All types seal by flow of the gasket surface caused by brute-force compressive loads. Loads actually must exceed the tensile strength of the gasket metal on the gasket-contact area. Therefore, surface finish of both flange and gasket is very important.

Round Cross Section, Solid Metal: These gaskets are generally made from round wire, cut to the length of the gasket circumference, then formed into a circle and welded. They provide positive, gas-tight seals at relatively low flange pressures. Since only line contact occurs, they have high local seating stress at low bolt loads. The contact faces increase in width as the gasket is compressed, effectively flowing into flange faces.

Solid Metal, Heavy Cross Section: These are usually rectangular or triangular-shaped gaskets, machined in heavy cross sections from solid metal. They are used for high-pressure and high-temperature services where operating conditions require special joint designs.

The gaskets usually seal by line contact or wedging action which causes surface flow. Some of them are pressure-actuated; i.e., the higher the pressure, the tighter the joint.

Light Cross Section, Pressure-Actuated: These metallic gaskets are used in place of elastic O-rings in sealing extremes such as vacuums and very high temperatures or pressures. They can also be used when standard metal gaskets are ruled out because too-great flange loads are required.

STATIC O-RINGS (METALLIC)

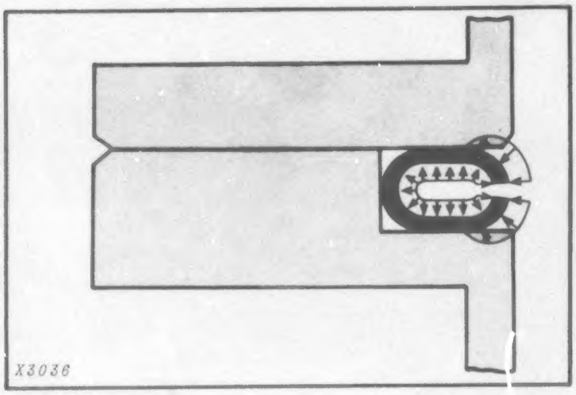


Fig. 56 — Typical Metallic O-Ring In Static Use

For a static seal that will meet extreme conditions of temperature, pressure and corrosion with low cost and simplicity, the metallic O-ring is widely used. (Fig. 56).

Metallic O-rings are made of metal tubing which is formed into circular or other required shapes; the two ends are then butt-welded, and the weld ground flush.

A typical application places the metallic O-ring in axial compression between parallel faces which are square to the fluid passage or vessel axis. The seal is usually located in a counterbore or closed groove on one face, or in a retainer, which eliminates the need for machining a groove.

Operation

When compressed, the seal tubing buckles slightly, resulting in two contact areas on each seal face, and maximum contact stress between the seal and the mating faces (Fig. 56). The seal allows for some deviation in the sealed faces.

ENGINE CYLINDER HEAD GASKETS

Because engine cylinder heads are such an important use of gaskets, we will cover them separately in this section.

Types Of Head Gaskets

The engine cylinder head is retained on the block by bolts or studs and a gasket is placed between the mating surfaces to keep a water-, oil-, and gas-tight seal (see Fig. 53).

In early engines, the cylinder head gaskets were made of solid metal, usually soft copper or lead. These metals were ductile enough to conform to the head and block irregularities and served very well at the low combustion pressures of that time.

In later engines, the horsepower and consequently the combustion pressures and temperatures increased. The solid-type gasket no longer gave an adequate seal of the pressures within the cylinders.

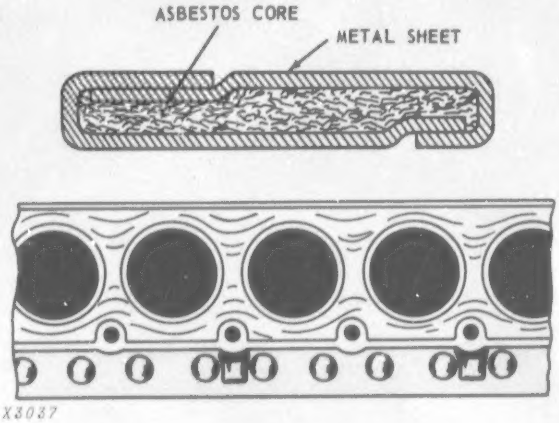


Fig. 57 — Typical Cylinder Head Gasket (Early Engines)

This led to the development of the fabricated gasket. It was constructed of thin soft copper sheets with an asbestos core as shown in Fig. 57.

This gasket had the resiliency for a tight seal and at the same time absorbed the engine head vibrations.

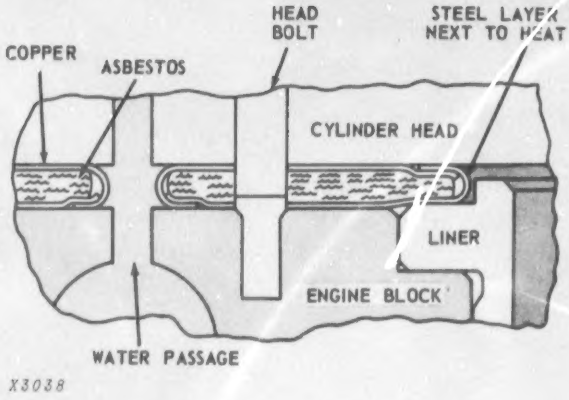

HEAD
BOLT
STEEL LAYER
NEXT TO HEAT
COPPER
ASBESTOS
CYLINDER HEAD
LINER
ENGINE BLOCK
WATER PASSAGE
X3038

Fig. 58 — Duofold Gasket

However, copper had disadvantages in gaskets. That portion of the gasket exposed to the heat of combustion tended to soften and burn out. To avoid this, tin-plated steel was used for the *bottom* layer nearest the heat. Copper grommets were used at the coolant openings to prevent the corrosive action of coolant on the steel.

Later development produced the type of head gasket illustrated in Fig. 58. In this type (Duo-fold), the bottom steel layer overlapped the combustion chamber openings, while the copper layer overlapped the coolant openings.

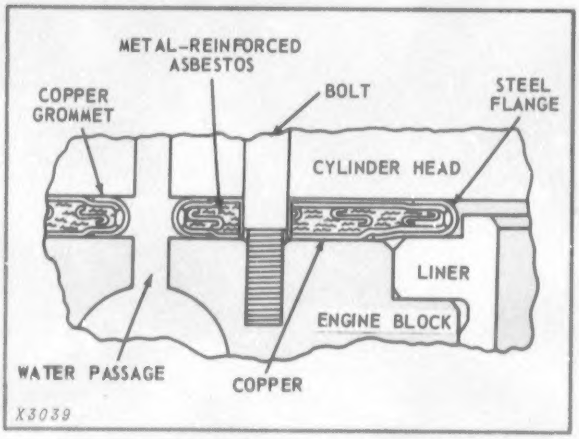

METAL-REINFORCED
ASBESTOS
COPPER
GROMMET
BOLT
STEEL
FLANGE
CYLINDER HEAD
LINER
ENGINE BLOCK
WATER PASSAGE
COPPER
X3039

Fig. 59 — Metal-Clad, Metal-Reinforced Gasket

A variation of the layer gasket which has a stronger construction is illustrated in Fig. 59. This became necessary because of the higher pressures in the combustion chambers.

This gasket has a top and bottom layer of copper or steel, with a steel flange at the combustion chamber openings, and copper grommets in the coolant and oil holes. The plain asbestos filler (core) is replaced with reinforced asbestos material. This keeps the asbestos from "squeezing out" when the head is tightened to the specified torque. This gasket usually is plastic-coated for effective sealing when the gasket is installed.

All of the above types of cylinder head gaskets are in common use today. However, since each engine demands a cylinder head gasket designed for its particular operation, some engines require more sophisticated types of gaskets. Some of these are described below.

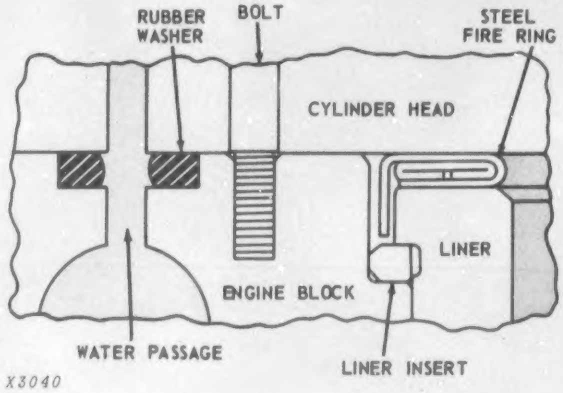

RUBBER
WASHER
BOLT
STEEL
FIRE RING
CYLINDER HEAD
LINER
ENGINE BLOCK
WATER PASSAGE
LINER INSERT
X3040

Fig. 60 — Fire Ring And Washer-Type Gasket

The cylinder head gasket design illustrated in Fig. 60 is commonly known as the fire ring and rubber insert type. It is a multi-sealing gasket which has laminated steel fire rings, rubber or neoprene washers, and a rubber or neoprene gasket around the perimeter of the head.

When assembled, the space between the surfaces of the head and block are from 0.002 to 0.010 inch (0.05 to 0.25 mm). The sleeves, water holes, oil holes, and block perimeter are counterbored to accommodate the sealing parts.

The counter bores for the sealing washers are back-tapered from the fluid passages. This keeps the seals from moving into the passages.

The perimeter gasket seals out dirt or other foreign matter and any inner fluid leakage which might develop.

This design is very satisfactory. However, one disadvantage is the number of parts. This can be a problem when the engine is assembled.

This design also requires more accurate machining and stronger structural design in the engine.

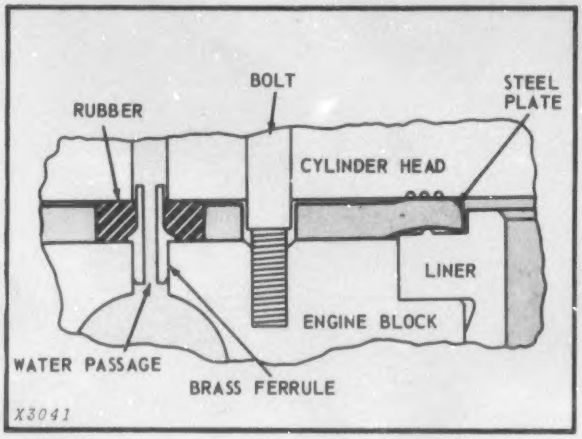

BOLT
STEEL PLATE
RUBBER
CYLINDER HEAD
LINER
ENGINE BLOCK
WATER PASSAGE
BRASS FERRULE
X3041

Fig. 61 — Steel Plate Gasket Construction

The steel plate gasket (Fig. 61) is another design of major importance. It consists of a heavy (0.050 to 0.080 inch [1.3 to 2 mm] thick) steel plate assembly. In effect, this is an integral firing ring in a carrier plate with washers and inserts to seal the fluids. The surface of the head and block engage a metal surface. The embossed ring at the cylinder openings keeps a high load on the sleeves to seal the combustion gases. The concentric grooves in the head lock the plate in position and increase the unit loading in this area.

The use of this type sealing requires precise machining of the head and block. Also, an accurate fit of the sleeves in the block is vital to reduce coolant leakage.

Care must also be taken to provide uniform sleeve standup from the block for uniform loading at each of the cylinders with a minimum of head distortion.

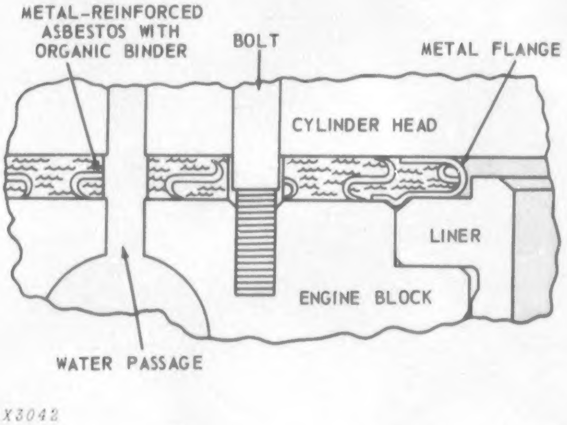

METAL-REINFORCED ASBESTOS WITH ORGANIC BINDER
BOLT
METAL FLANGE
CYLINDER HEAD
LINER
ENGINE BLOCK
WATER PASSAGE
X3042

Fig. 62 — Flanged Metal Reinforced Asbestos Gasket

Fig. 62 illustrates a different concept in head gaskets. This design has metal flanges for the combustion chamber openings. The body of the gasket consists of asbestos facing material on either side of a perforated steel core. This allows the combustion chamber flange to embed itself into the gasket body, providing contact and sealing of the coolant and oil openings in the rest of the gasket.

The asbestos surfaces are coated with antistick compound to aid in removal at disassembly.

When this type of gasket is retorqued, its compresibility is reduced. The gasket becomes denser and reaches a more stable condition. Beyond this point, loss of torque is negligible and the tendency to extrude is minimal. In effect, after retorquing, this gasket has the same advantages as the steel plate gasket and face-to-face design.

The composition and structure of the asbestos body eliminates the need for washers or inserts in oil or coolant openings; the use of metal grommets is limited to isolated holes.

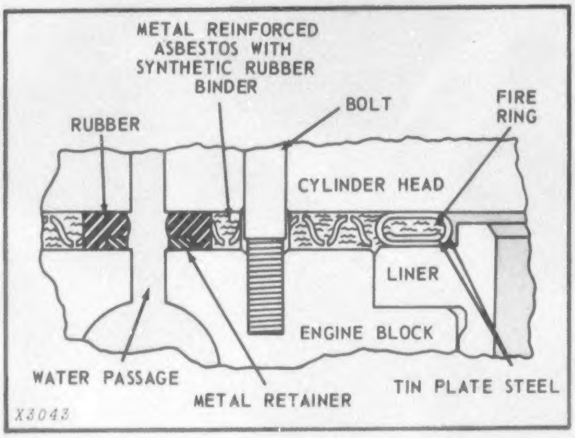

METAL REINFORCED ASBESTOS WITH SYNTHETIC RUBBER BINDER
BOLT
FIRE RING
RUBBER
CYLINDER HEAD
LINER
ENGINE BLOCK
WATER PASSAGE
METAL RETAINER
TIN PLATE STEEL
X3043

Fig. 63 — Fire Ring And Compressible Plate Gasket

A later gasket concept is illustrated in Fig. 63. This design has all of the advantages and features of the preceding ones.

It has separate fire rings, with asbestos cores, and an asbestos "plate" gasket. All of these are compressible.

The individual fire rings are constructed with a fold-over flange having a core of multiple layers of steel and asbestos washers in suitable combination.

The plate gasket itself can seal the coolant and oil, or it can have washers or inserts at the various openings.

The plate section of the gasket consists of synthetic rubber-bound asbestos facings on either side of a perforated core. The surfaces have an anti-stick coating.

The individual fire rings with the asbestos core can compensate for differences in sleeve standup from cylinder to cylinder.

A current head gasket design is shown in Fig. 64. This gasket contains a separate fire ring protected by a stainless steel plate nearest the combustion chamber openings.

The gasket consists of asbestos facing material with a steel core for reinforcement. The asbestos surfaces are coated with antistick compound to aid in removal at disassembly.

The composition and structure of the asbestos body eliminates the need for washers or inserts in the oil or coolant openings.

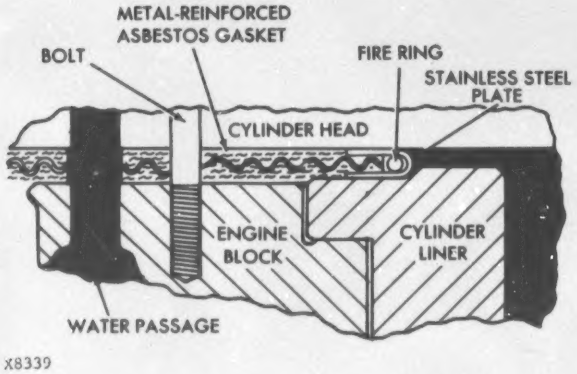


Fig. 64 — Fire-Ring Type Gasket

Maintenance Of Head Gaskets

Cylinder head gaskets require care in handling and installation.

When replacing a head gasket that has failed, always try to determine the cause of the failure. This could be due to not retorquing after installation or improper torque procedure. Proper torquing of head bolts will be discussed later.

Head gasket failures also can be attributed to increased cylinder combustion pressures caused by the installation of superchargers or blowers. Sometimes failure can also be caused by overfueling in diesel engines to increase horsepower.

Installing Cylinder Head Gaskets

1. When the head is removed, **discard the gasket.** While it may look good, invisible factors can lead to early failure if it is re-used.

2. Be sure that the surface of the engine block and head are scraped and wiped clean to remove any traces of gasket or sealer. Look for any scratches or nicks. If necessary, check the surfaces for warpage or heat cracks.

3. Be sure decks of head and block are flat. These surfaces may be reclaimed by milling or surface grinding. If this is done, check valves and adjust to correct depth.

4. Install cylinder liner so flange is flush (or a few thousandths of an inch above) the top deck. Make sure counterbores are clean, flat, and free of cracks.

5. To assure proper clamping force when head is connected to block, check that head-bolt bosses, hard washers (if used), and underhead of bolt are flat.

6. Clean head-bolt holes in block. Water or oil left in hole could cause block to crack because of hydraulic pressure created when bolts are tightened.

7. **Be sure that you have the right gasket.** Minor changes are often made in gaskets which, if not compatible with the engine, could cause heating problems. Information on the correct gasket is obtained from the parts catalog. Inspect the gasket for shipping or other damage. Never use a damaged gasket. As a final check, compare the new gasket with the old one; be sure all holes match.

8. Unless instructed by the engine Technical Manual, **do not** use any sealing medium on the gasket.

9. Position the gasket on the engine block (Fig. 65). Be sure that it is fitted over the locating dowels (if present) and that the correct end is to the front of the engine. Some gaskets are symmetrical and will fit either way without damage. But it is possible that some gaskets, even though they fit either way, if installed incorrectly will close off water or oil passages and cause engine damage. Unless otherwise instructed, install the **smooth** side of the gasket to the block of the engine.

NOTE: Always consult the engine Technical Manual for specific instructions.

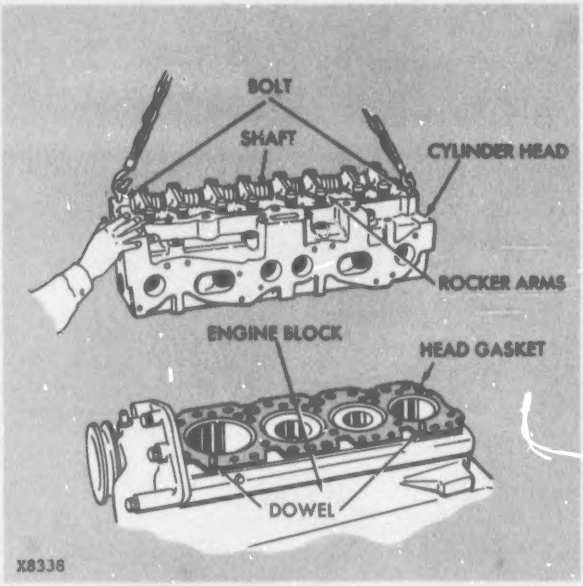


Fig. 65 — Installing Engine Cylinder Head Gasket

10. If block has no dowels, position gasket by holding fire rings concentric and around outside of the fire dam (not flange) on liners.

11. Carefully install the cylinder head on the block without disturbing the gasket (Fig. 65). Use long bolts with heads cut off to guide head onto block. Use a chain hoist or similar tool to lower head so it is parallel to block. Be sure the threads of the attaching studs or cap screws are smooth and clean. Coat the threads with oil or white lead for lubrication (if recommended). Install the cap screws or stud nuts and tighten until **just snug.**

12. Tighten each bolt or nut only about one-half turn at a time. **Start at the center of the head and work out to both ends of the head until the specified torque is reached.** Fig. 66 shows the general sequence in tightening cylinder heads.
Tightening the head bolts in one step may distort the head or cylinder liners and result in compression leaks.

13. After the engine has operated long enough to reach operating temperature, the cylinder head cap screws or nuts should be retorqued. A more effective method is to operate the engine for a specified period. For example, one manufacturer recommends a break-in as follows: two hours of break-in with the first half hour under no load, the second under half load, and the last hour under ¾ to full load (dynamometer or otherwise). Then retorque the head bolts.

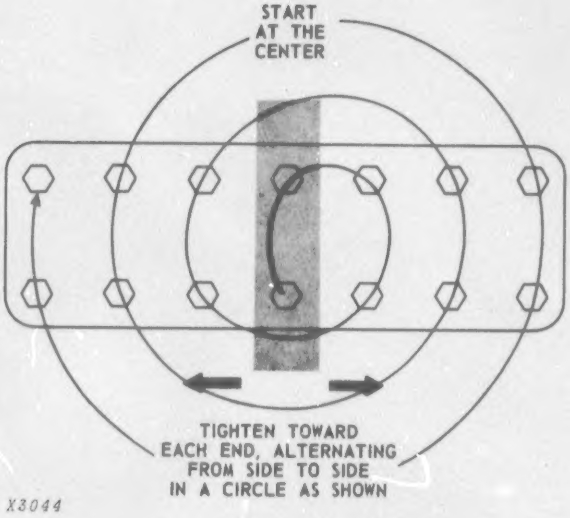

START AT THE CENTER
TIGHTEN TOWARD EACH END, ALTERNATING FROM SIDE TO SIDE IN A CIRCLE AS SHOWN
X3044

Fig. 66 — Guide To Proper Sequence For Tightening Cylinder Head Cap Screws

When retorquing, **always** loosen the bolts before drawing up to specified torque. This will insure a more uniform torque on each bolt.

Why Retorque Cylinder Heads?

The real purpose for torquing head bolts is that it provides for a uniform and controlled "squeeze" on the head gasket. When torque is applied to a bolt, some of the turning force is changed to pressure on the gasket, and some of the energy is used up in friction in the threads and under the bolt head. The portion of the turning force which puts a clamping force on the gasket "stretches" the bolt.

Remember, however, that the bolt acts like a spring. The drawing in Fig. 67 illustrates this. Shown are two head bolts of different lengths — 5 inches and 2½ inches. Initially they are torqued *equally*, say to 115 ft.-lbs. (156 N•m). Torqued equally, each bolt will "stretch" equally — *for each inch of its length.* But since the 5-inch bolt is twice as long as the 2½-inch bolt, the 5-inch bolt stretches twice as much. For this diameter bolt and for this torque, the stretch is about 0.002 inch per inch of bolt length. Therefore, the 5-inch bolt stretches 0.010 inch (0.002 x 5 = 0.010) while the 2½-inch bolt stretches 0.005 (0.002 x 2½ = 0.005). The head gasket is now held properly and with uniform forces.

But something happens after the engine is thoroughly warmed up and operated on a dynamometer and under load for about an hour. The head gasket begins to settle in place, "flowing" into the uneven areas on the surface of the cylinder head and block. As it settles in place, the cylinder head moves a little closer to the cylinder block.

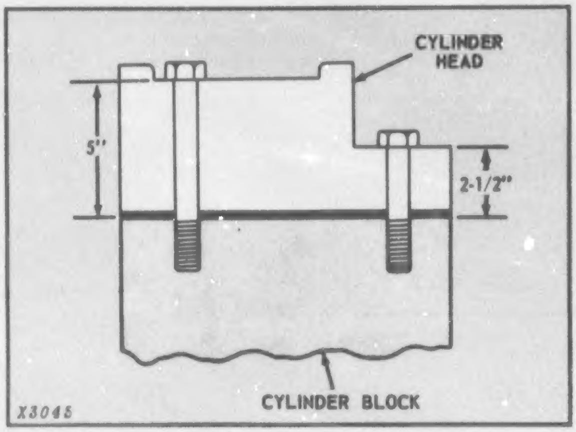


Fig. 67 — Longer Head Bolts "Stretch" More When Torqued

Let's say that the head settles evenly 0.004 of an inch (0.1 mm) (which is why valve clearances must be reset). This settling takes some of the original "stretch" out of the head bolts. To determine the stretch remaining in each bolt, subtract this from the total stretch shown in the chart below.

It should now be clear that the short bolt has lost, relatively, much more of its original "stretch," (and original torque) than the long bolt, so the gasket is now being squeezed considerably less by the short bolts than by the long bolts.

	5-Inch Bolt	2½-Inch Bolt
Stretch (torqued)/in.	.002"	.002"
Total Stretch (torqued)	.010"	.005"
Gasket relaxation after warm-up (under load)	.004"	.004"
Stretch remaining	.006"	.001"
Percent of original stretch remaining	60%	20%
Retorque	100%	100%

This problem of bolt "stretch" can never be corrected by **over-torquing** head bolts. This only causes the bolts to be "stretched" beyond their point of resilience.

Retorquing after a warm-up is the only practical solution — and don't forget to *break the bolts loose before retorquing.*

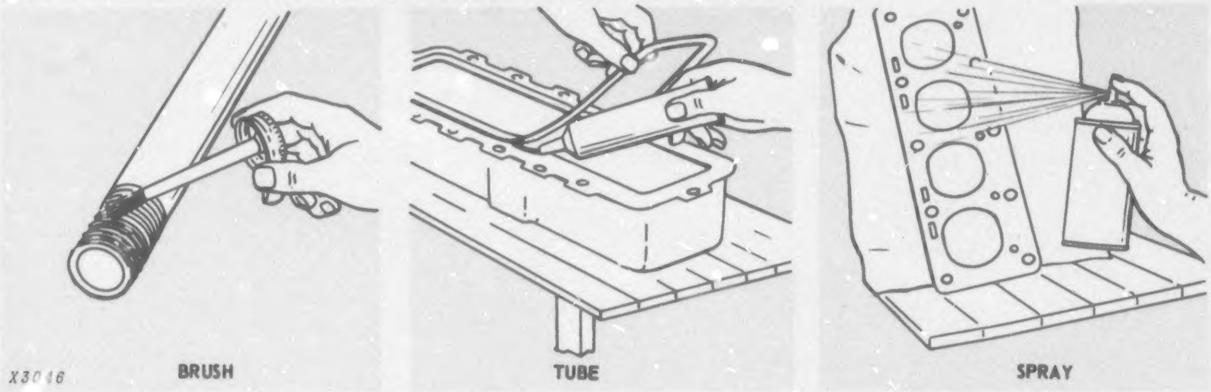


Fig. 68 — Sealants Are "Gaskets" Which Are Applied In Liquid Or Paste Form

SEALANTS

Our third major section of "Seals" is **sealants,** which we will cover now.

Sealants are similar to gaskets, except that a sealant is **applied** as a liquid or paste, while a gasket is usually precut to fit and is always placed between mating surfaces.

However, solid *sealing tapes* are also considered as "sealants" in this section because they are not cut to size and are also used to cover seams.

Another type of "sealant" is the *adhesive,* which is used for its holding power rather than its ability to seal.

The *jobs* of sealants are similar to those of gaskets: exclude dust, dirt, and moisture — or contain a liquid or gas. However, unlike gaskets, sealants are *also* used as protective coatings, to reduce noise, to improve appearance, and to perform a joining function.

Sealants are normally used for less severe conditions of temperature and pressure than gaskets (there are exceptions). But sealants are often more resistant to chemicals and are more economical to use than gaskets.

TYPES OF SEALANTS

The major categories of sealants are:

- **Hardening types**
- **Nonhardening types**
- **Tapes**

Whether a sealant is hardening or nonhardening depends upon its chemical composition and curing characteristics, rather than on its initial form. Sealants generally come in nonsolid forms in a wide range of viscosities. Some epoxy sealers come in powdered form and must be melted when applied Certain asphalt-based sealers and waxes are solid, and are applied by a hot-melt system. Thermosetting film adhesives used for sealing also come in tape form, and they generally require heat and pressure for curing.

Hardening Types

These sealants can be divided into two classes:

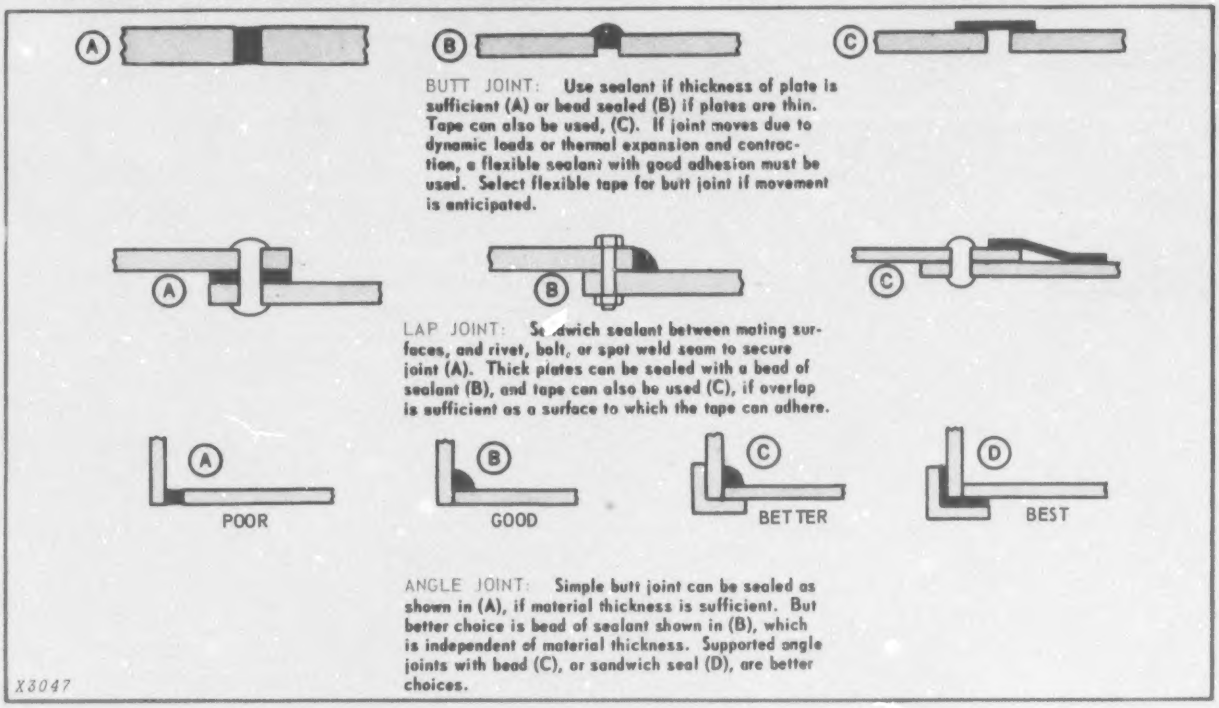
- **Rigid — which cure or set up firm.**
- **Flexible — which remain flexible after cure.**

RIGID or hard-setting sealants are characterized by their inability to flex. They crack if flexed, and are often difficult to remove. Some — notably the expoxies can join as well as seal.

Common rigid sealants which are distinctive to this group are those based on components of epoxies, polyesters, acrylics, polyamides, and polyvinyl acetates (PVA).

FLEXIBLE sealants remain flexible after curing, and have elastic bases. Their range of flexibility varies considerably, as does hardness. Some of these sealants are true rubbers; many have good adhesive qualities; and all can be compounded to resist a variety of environmental conditions.

The flexible sealants are either true elastomers — that is, they return to their original shape after being deflected — or are characterized by an ability to deform or stretch without tearing, but do not return to their original shape.



BUTT JOINT: **Use sealant if thickness of plate is sufficient (A) or bead sealed (B) if plates are thin. Tape can also be used, (C). If joint moves due to dynamic loads or thermal expansion and contraction, a flexible sealant with good adhesion must be used. Select flexible tape for butt joint if movement is anticipated.**

LAP JOINT: **Sandwich sealant between mating surfaces, and rivet, bolt, or spot weld seam to secure joint (A). Thick plates can be sealed with a bead of sealant (B), and tape can also be used (C), if overlap is sufficient as a surface to which the tape can adhere.**

ANGLE JOINT: **Simple butt joint can be sealed as shown in (A), if material thickness is sufficient. But better choice is bead of sealant shown in (B), which is independent of material thickness. Supported angle joints with bead (C), or sandwich seal (D), are better choices.**

Fig. 69 — Common Ways Of Sealing Joints

Nonhardening Types

These soft-setting sealants stay "wet" after application and never truly dry. They generally cannot be depended on to perform a joining function, although some formulations are used as adhesives in very low-stress joints.

These sealants are characterized by the "mastic" type pastes usually applied to seams with a trowel or brush.

Tapes

Tapes are available in a variety of backings and adhesives — usually in pressure-sensitive or solvent-activated adhesive backs. Self-sticking tapes are also made.

Some nonhardening sealants are formulated so that they can be packaged in "tape" form. These are not adhesive-backed and can be easily thumbed into place.

JOINTS FOR SEALANTS

Joints to which a sealant can be applied depend to a great extent on the type of sealant.

For example, a free-flowing sealant cannot be applied to a vertical surface; a nonsagging type must be used.

Typical common joints are the simple butt joint, and the lap joint (Fig. 69).

Lap joints can be most easily sealed with tape; fillet-sealed, if the thickness of the joined sheets will support a bead of sealant; and sandwich-sealed. Sandwich sealing is a common method with structural adhesives. Where ordinary sealants are used, the sealing material is brushed, extruded, troweled, or thumbed on, and the lap joint made and mechanically secured with rivets, or bolts and nuts.

Sealant thickness is more critical when material is applied between surfaces. However, where sealant thickness is not critical, curing time can be delayed considerably by overly thick applciations of the material.

If lap joints cannot be sandwich-sealed, the joint should have a built-in receptacle to receive the sealant.

Voids can result in a joint unless care is taken during application. When beads of sealant are laid in a joint, and air spaces are unavoidable, tooling the sealant before it cures helps to fill the cavities.

When applying sealant, always follow the manufacturer's instruction for proper steps in placing and curing.

USES OF SEALANTS

An inside sealer keeps in a fluid or other medium; an outside sealer keeps out contaminants; some sealers perform both functions.

However, sealants can be used to perform other functions, some of which are almost as important as the primary role of sealing. These are: *(1) Joining; (2) Electrical or thermal insulating; (3) Noise reduction; (4) Vibration dampening; (5) Expansion and contraction control; (6) Smoothing and filleting; (7) Protective coating; (8) Tampering prevention.*

Where conditions are not too severe, sealants can often do the job better and more cheaply than gaskets.

TEST YOURSELF

QUESTIONS

1. What are the two **basic** types of seals?

2. Explain the difference in the two basic types of seals.

3. Why should a piston rod seal allow slight leakage of a fluid film?

4. True or false? "As a general rule, replace all seals that are disturbed during repair of a system.'

5. How do piston rings seal?
   - a. By springing out against the cylinder wall.
   - b. By squeezing in against the piston ring groove.
   - c. By sealing against the side of the piston ring groove.

6. True or false? "In dynamic uses, the O-ring should be able to roll in its groove."

7. Which are normally used to seal higher pressures?
   - a. Metallic gaskets
   - b. Nonmetallic gaskets

8. When torquing cylinder head bolts, what is the best sequence?
   - a. Start at each end and work to the center.
   - b. Start at the center and work toward both ends.
   - c. Start at one side and work across.

9. Why must all cylinder head bolts be tightened to the same torque?

10. How do sealants basically differ from gaskets?

(Answers on next page.)

ANSWERS TO PART 1 QUESTIONS

1. (Any three of these.) a. Support the moving part, b. reduce friction, c. reduce wear, d. provide a replaceable wear surface.

2. Axial and radial loads.

3. Full-film lubrication which is created by hydrodynamic pressure.

4. Improve heat dissipation, insure that bearing remains round and avoid the possibility of bearing movement.

5. Size of bearing, number of rolling elements and type of races.

6. The full-type bearing, because of its loading slot, cannot take thrust loads as well as the Conrad bearing.

7. The inner race is going to be the press fit on the shaft because normally the press-fit race is **pressed** into the rotating part and the push-fit race is **pushed** into place.

8. Force the bearing on the shaft by pressing on the outer races — only press on the race that is the press fit.

9. Fatigue failure.

10. A distorted housing or shaft.

ANSWERS TO PART 2 QUESTIONS

1. Dynamic and static.
2. Dynamic seals are used to seal **moving** parts, while static seals are for sealing **fixed** parts.
3. To lubricate and cool the moving parts and to prevent seal wear.
4. True.
5. a. By springing out against the cylinder wall, and
   c. By sealing against the side of the piston ring groove.
6. True.
7 a. Metallic gaskets.
8. b. Start at the center and work toward both ends.
9. To put a uniform "squeeze" on the head gasket for a good seal.
10. Sealants are applied as a **liquid** or **paste**.